

Dispersal Ecology of Greater Sage-Grouse in Northwestern Colorado: Evidence from Genetic and Demographic Methods

2006 Annual Progress Report
(March through December 2006)



Thomas R. Thompson
Graduate Research Assistant
Fish & Wildlife Resources
University of Idaho, Moscow
thom6711@uidaho.edu

INTRODUCTION

Over the last 30 years declines in greater sage-grouse (*Centrocercus urophasianus*) populations have occurred across much of their range (Connelly et al. 2000). Connelly and Braun (1997) estimated breeding populations had declined by 17-47% since the mid 1970s, a trend that has paralleled significant changes in the sagebrush habitats essential for the species. The primary factors affecting this change in sagebrush habitats differ by region and state but include changes in fire regime, conversion to cropland and seeded grasslands, wild and domestic ungulates, removal of sagebrush to increase livestock production (mechanical and herbicide methods), range conversion by invasive exotic plant species like cheatgrass (*Bromus tectorum*), and general anthropocentric encroachment (e.g. excessive hunting, roads, and mineral exploration and extraction) (Crawford et al. 2004). The result of these changes has been a progressive range-wide loss, fragmentation, and degradation of sagebrush habitats (Braun 1998).

In response to population declines, recent research on sage-grouse has focused on the population ecology, habitat relationships, and response to management practices by this species. Research has provided key guidelines (Braun et al. 1977, Connelly et al. 2000) for specific habitat requirements and vegetation characteristics for nesting, brood rearing, and wintering habitats needed to sustain healthy populations. In addition, these studies have documented that by providing suitable habitat within these seasonal periods sufficient survivorship and productivity within age and sex classes can be maintained. However, the mechanisms, patterns, and consequences of movements between these seasonal patches, especially among juveniles during natal dispersal, and the effects of this movement on survival, recruitment, the redistribution of individuals, as well as the population dynamics within and between populations remains largely unknown.

Natal dispersal has been defined as the one-way movement of juvenile individuals from their natal area (i.e., birth site) to first breeding site without return (Howard 1960, Greenwood and Harvey 1982). Among avian species in which natal dispersal has been documented, females normally disperse greater distances and at higher proportions than males, who are the more philopatric of the sexes (Greenwood 1980, Johnson and Gaines 1990, Clarke et al. 1997). Natal dispersal is a fundamental life history process that has

important consequences at both the population and individual level of a species (Clobert et al. 2003). At the population level natal dispersal helps to regulate and maintain gene flow (Piertney et al. 2000, Blundell et al. 2002), population persistence and colonization (source-sink dynamics) (Dieckmann et al. 1999, Martin et al. 2000, Segelbacher et al. 2003) and the dispersion of individuals and populations across a landscape thus influencing the structure of the spatial genetic and population dynamics of a species (Johnson and Gaines 1990). At the individual level, natal dispersal is a trade off between costs, such as increased mortality and lower fitness, and benefits, such as inbreeding avoidance and reduced competition for resources. For most species the ecology and ultimate management implications of the dispersal process remain unanswered, despite its importance in the ultimate demographic, behavioral, and evolutionary processes of a species (Fahrig and Merriam 1994). The study of dispersal is a challenging endeavor due to the often highly mobile nature of a species, the variability of movement between individuals, and the large spatial scales at which this process can take place (Yoder 2004).

Quantifiable data and information on juvenile dispersal and survival in the greater sage-grouse is one of the least understood aspects of this species life history (Dobkin 1995). In a recent review of literature pertaining to sage-grouse (Rowland and Wisdom 2002) only 8 citations out of 742 covered dispersal and only 2 of these (Dunn and Braun 1985, 1986) were cited in a peer reviewed journal. In Colorado, Dunn and Braun (1985) found females on average dispersing further than males (8.8 km vs. 7.4 km), but found no difference in the proportion of males and females returning to the lek closest to their capture site (i.e., natal-lek area) (58.3% returned). In addition, recruitment of juveniles to their natal-lek areas varied from 53% to 100% (Dunn and Braun 1985). Despite the difference in mean distances of dispersal between the sexes, these initial findings would suggest that both sexes of sage-grouse are philopatric to their natal-lek area and that proportions of individuals undertaking natal dispersal are less than would be expected based on natal dispersal predictions of Greenwood (1980) and Johnson and Gaines (1990). However, the results from this study are based on low sample sizes of radio-marked ($n = 24$) and color-banded juveniles during a single year in one population, as well as the critical assumption concerning the natal-lek area being equivalent to lek of

actual breeding and/or nest site (Dunn and Braun 1985). In addition, dispersal studies of banded individuals are often biased low due to decreasing detectability away from a study site often biasing estimates of dispersal parameters (Kenward et al. 2002). Besides this one study no other empirical information is available on natal dispersal and survival in juvenile sage-grouse.

Two other studies have investigated natal dispersal among prairie grouse. In Wisconsin 260 juvenile greater prairie-chickens were radio-marked and females dispersed at higher frequencies and greater distances compared to males (6.9 km vs. 2.3 km, respectively; Halfmann 2002). However, less than 15% of dispersing juveniles left their natal subpopulations (Halfmann 2002). Similarly in a study on the lesser prairie-chicken, the mean dispersal distance was greater for females than males (13.7 km vs. 1.4 km, respectively; Pitmann 2003). In both studies, a bimodal pattern of dispersal was observed. In the fall phase of dispersal there was no difference between the sexes, however during the spring phase of dispersal there were gender specific differences in movement patterns in both species (Halfmann 2002, Pitmann 2003). In addition, over-winter survival (October through March) of juvenile lesser prairie-chickens did not differ between the sexes, or between juvenile and adult birds (Pitmann 2003).

Dispersal patterns and recruitment processes of juvenile sage-grouse, as well the landscape characteristics that influence and contribute to these movements remain lacking. Knowledge of the dispersal ecology (timing, distances moved, frequency and rate of movement, immigration and emigration rates within and between populations, and juvenile survivorship) will provide better information on how to manage this species at the landscape level, as well as within and between populations. This information will be useful in attempting to improve and plan for the conservation of this species as its habitat becomes more fragmented and altered. Without detailed knowledge of the dispersal ecology of juvenile sage-grouse (independence from brood, timing of movements, distances moved, frequency and rate of movement, immigration and emigration rates, survivorship, dispersal success) planning for the conservation and management of this species into the long term will become more difficult. Thus, the main objectives of this study are:

- 1) To determine the sex-specific movement patterns of juvenile sage-grouse during natal dispersal including timing, duration, rate of movement, distances moved and recruitment rate,
- 2) To determine the effects of these dispersal patterns on survival rates and causes of mortality, and
- 3) To determine how landscape structure influences both the movement patterns and survival of juveniles during this period.

In addition to investigating natal dispersal in juvenile greater sage-grouse this study is also determining the feasibility of supplementing successfully nesting female's broods after hatching with wild sage-grouse chicks that were hatched in captivity (i.e., domestically-hatched) as an alternative to translocating adult birds into declining populations. Historical and recent translocation efforts have focused on trapping reproductively active birds from stable populations and translocating them into declining ones (Musil et al. 1993, Reese and Connelly 1997). Efforts at translocation have been relatively unsuccessful (5-12% reported by Reese and Connelly 1997) given the high site fidelity of adults to traditional breeding, nesting, and wintering areas, inexperience of yearling birds to new breeding grounds (i.e. lowered nest initiation rates), and the long range movement patterns that the species is capable of making across a landscape (Patterson 1952, Musil et al. 1993). Reese and Connelly (1997), in light of these difficulties, have made several recommendations to increase the success of any given translocation, but still viewed them as experimental and limited in their ability to substantially increase population numbers.

As a potential alternative to translocation, augmenting broods with domestically-hatched chicks would have the following potential benefits: (1) increased survival of brood-mates by reduced risk due to "dilution" of broods, increased predator detection, or reduction in exposure time depending on date of introduction into a surrogate brood (i.e., during pre-flight development), (2) increased familiarity to brood-rearing areas, dispersal and migration routes and corridors, wintering areas, and breeding areas from early contact with the female, brood-mates, and local juveniles and adults, (3) increased proportion of yearlings successfully breeding (i.e., initiating a nest for females and

establishing a territory on a lek for males) compared to translocated yearlings, and (4) less restrictions and concerns about what populations could take advantage of this management option (not just non-migratory, isolated, and buffered populations). However, the feasibility and benefits of this method have not been widely and rigorously tested in avian species including upland game bird species. The main issues determining whether the feasibility and benefits of this method can be tested depends on (1) the successful hatching of wild sage-grouse chicks in captivity, and (2) the successful adoption and acceptance of unrelated offspring into sage-grouse broods.

Successful hatching and raising of wild sage-grouse chicks has been accomplished in 2 previous studies investigating feeding habitats of young birds (Huyer (2004) with chicks and Johnson and Boyce (1990, 1991) with chicks and juveniles). With the recent dramatic declines in Gunnison sage-grouse in Colorado and the range-wide declines in the greater sage-grouse, the Colorado Division of Wildlife has started developing procedures and testing pilot studies on captive rearing of young sage-grouse. These pilot studies have demonstrated that greater sage-grouse eggs can be collected, incubated, hatched, and chicks returned to surrogate wild broods successfully (Tony Apa, personal communication). However, the frequency, mechanisms and conditions, and effect on survival and movement patterns of adoption in sage-grouse have not been investigated. The objectives for this part of the study are:

- 1) To verify and evaluate the mechanisms and conditions of adoption in wild broods through the introduction of domestically-hatched chicks and observation of natural adoption rates,
- 2) To assess the movement patterns and survivorship of successfully adopted domestically-hatched ≤ 4 day and ≥ 5 day-old chicks from the natal area of the surrogate brood to chick independence and brood break-up (approximately 16 weeks of age).

STUDY AREA

This study is being conducted at 2 sites in Moffat County, Colorado located in the extreme northwestern corner of the state (Figure 1). The study sites were selected for the

following reasons: (1) Moffat county has the highest density of greater sage-grouse and sagebrush habitats in Colorado (Braun 1995), (2) populations within the county and at both sites have annually been surveyed during lek counts by Colorado Division of Wildlife since the mid 1970s, (3) a population dynamics, habitat use, and movement study of sage-grouse was recently completed within the county (Hausleitner 2003), (4) the distance between the 2 sites represents a compromise between the need for independence between sites (i.e., sites can act as replicates) as well as accessibility (i.e., both sites are within 1 ½ -2 hour drive of the field station), and (5) both study sites have strong cooperation between private landowners and state and federal agencies operating on 'working' landscape.

The Axial Basin/ Danforth Hills study site is located 30 km southwest of Craig, Colorado in the southeastern portion of the county, while the Cold Springs Mountain site is located in the northwestern portion of the county. Study sites are separated by a maximum straight-line distance of approximately 100 km. The Axial Basin/ Danforth Hills site consists of a rolling topography ranging from 1,800 – 2,350 m in elevation. The Axial Basin encompasses the northern and eastern portion of the study site and is bounded by Highway 40 to the north and Highway 13 to the east. The northernmost area of the Danforth Hills comprises the south and southwestern portion of the study site and ranges in elevation from 2,000 to 2,350 m. The Cold Springs Mountain study site encompasses the eastern edge of the Uinta Mountain Range that extends approximately 30 km into the northwest corner of Colorado. Topography consists of mountainous areas, rolling hills, and mesas ranging in elevation from 1,900 – 2,900 meters. Numerous canyons and drainages including Talamantes Creek bisect the region running generally west to east across the landscape. The study site is bounded by the Green River to the south and Vermillion Creek to the east. To the west the study extends approximately 5 km into Dagget County, Utah including Willow Creek and the Bender Mountains, and to the north approximately 6 km into Sweetwater County, Wyoming including Kinney Rim, Horseshoe Basin, Four-J Rim, and Pine Mountain.

The climate of northwestern Colorado is semiarid receiving 20.3 to 50.8 cm of precipitation annually depending on elevation (Western Regional Climate Center 2003). The mean annual temperature for Moffat County is 6.3C (Braun and Hoffman 1979), but

can be less in areas of higher elevation like Cold Springs Mountain (4.4C) (U.S. Department of Interior 1978). Annual average precipitation and temperature fluctuate widely within and among years making drought a frequent occurrence. Big sagebrush (*Artemisia tridentata* spp.) rangeland communities within the county comprise approximately 60% of the land area while the remaining area is comprised of pinyon (*Pinus edulis*) –juniper (*Juniperus* spp.), aspen (*Populus tremuloides*), spruce (*Picea* spp.), mountain shrub communities with Gambel’s oak (*Quercus gambelii*), serviceberry (*Amelanchier* sp.), snowberry (*Symphoricarpos oreophilus*), and chokecherry (*Prunus virginiana*) (Hausleitner 2003). A combination of private landowners and state and federal [i.e., Bureau of Land Management (BLM)] agencies oversee the use and management of the land in the county. Federal and state agencies administer approximately 60% of land (BLM being the largest holder at 46.8%) with private landowners make up the remaining 40%. Land use is primarily cattle and sheep production, agriculture (e.g., small grain and hay farming, and Conservation Reserve Program (CRP) lands primarily in the southeastern portion of the county), mineral exploration and extraction, and ecotourism (hunting, fishing, and outdoor recreation activities). The major impacts affecting the sagebrush rangeland communities include cattle, sheep, horse, and wild ungulate [mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*)] grazing, herbicide and mechanical application, fire, and mineral exploration and extraction.

METHODS

Capture Techniques of Adult Sage-Grouse

Female greater sage-grouse were trapped near or on known active leks within the Axial Basin/ Danforth Hills, Cold Spring Mountain, and North Moffat study areas. Trapping took place during mid to late March and early April during peak female attendance at leks. Sage-grouse were captured by spotlighting and using long-handled hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Captured females were aged as yearling or adult by examining the condition of the outer primaries (Patterson 1952, Dalke et al. 1963) and fitted with numbered aluminum legbands and <

18 gram, 540 day ATS (Advanced Telemetry Systems, Inc.) necklace-mounted transmitters (Connelly et al. 1993). In addition, 2-3 drops of blood were collected by clipping the back toenail and stored in EDTA tubes for genetic analyses.

Nest Monitoring of Primary Hens

Birds within each study site were monitored by a 2 person field crew. A 3-element yagi antenna and portable receivers were used to locate and monitor females and a handheld Global Positioning System (GPS) unit to record locations. Radio-marked females were monitored every 2-3 days starting April 1 to determine nesting status by walking within 50 m and circling the bird without flushing it. Once a female had been identified as possibly initiating a nest (2-3 locations near the same spot), the specific location was confirmed by observing the female on the nest. Females that were confirmed as nesting were monitored every 3-4 days from a distance of >100 m until fate of the nest was determined (i.e. abandoned, depredated, or successful).

Egg Acquisition

The protocols used for egg acquisition were similar to those developed by Huwer (2004). This protocol has been approved by the University of Idaho and the Colorado Division of Wildlife Animal Care and Use committees. Eggs were primarily collected from the North Moffat study site, although in 2006 eggs were also collected from designated egg acquisition females in the other study areas. Females were monitored every 1-2 days until a nest was found. Females were located between 0800 and 1100 by circling within 15-20 m and recording the position. This position was then searched later in the day when the female was off the nest to verify if a nest was present. Once a nest with eggs was located, eggs were removed and replaced with fake latex eggs. This procedure was repeated 1- 2 days during afternoon hours until the desired number of eggs were collect (3-4). Females continued to be monitored for 1-2 weeks post-egg removal to determine renesting status.

Egg Storage and Incubation

Collected eggs were stored at 10 to 15⁰ C and turned twice a day (Harvey 1993). Collected eggs were stored until hatching dates of nesting primary hens in the Axial Basin were determined to synchronize incubation periods and hatch dates. Collected eggs were incubated in a 1502 Sportsman cabinet incubator owned by CODW. Eggs were incubated at 37.5⁰ C, 58% relative humidity and turned every 4 hours during the first 24 days of incubation (Huwert 2004). To achieve 15% egg-mass loss as recommended by Harvey (1993), small adjustments in humidity were made and eggs were monitored periodically (i.e., weighed every 5 days) to determine mass loss and development (Huwert 2004). During the final days of incubation (day 24–28) eggs were removed to a 1550 Sportsman Hatcher.

Chick Protocol for Domestically-Hatched Chicks

Hatched chicks were left in the hatcher for approximately 12-24 hours to dry. They were then individually marked, weighed to nearest 0.01 gram, and moved to the brooder. Day-old chicks were placed in 2.5 x 1.5 m rectangular pen under natural conditions (i.e., natural vegetation, substrate, weather) on the afternoon of day 1 and provided with a decoy female brooder for thermoregulation (35⁰ C) and imprinting. In the evening chicks were collected from the outside brooder, weighed, and placed in an identical brooder and pen setup inside the grouse house for protection from nighttime predators, as well as weather extremes. Chicks were provided with 14-16 hours of feeding opportunities (sunrise to sunset) under natural conditions and good weather (i.e., no precipitation and temperatures above 10⁰ C). A mixture of crickets, meal worms, wax worms, and chopped forbs and alfalfa, as well as water were made available to the chicks every hour. In addition, the outside and inside brooders were supplied with heating pads and heating lamps (inside decoy brooder), as well as shade and water to provide areas for thermoregulation. Interactions with field technicians were minimal to reduce imprinting of chicks on humans. On the day chicks were introduced into surrogate wild broods a 1.4 gram, 60-day radio-transmitter was attached with 2 sutures along the dorsal midline between the chick's wings following the procedure of Burkepille et al. (2002). Chicks were introduced into wild broods during the evening to facilitate brooding by the

surrogate females. This involved capturing part or all of the brood and then releasing all chicks (wild and domestic) back to the female after several minutes.

Domestically-hatched chicks were held in captivity for either \leq to 4 days (treatment 1) or \geq 5 days (treatment 2). The assignment of treatment and length of time individual chicks were held in captivity was dependent upon several factors: (1) the condition of the chick (chicks with low hatch weights, low weight gains, or slight deformities such as partially splayed legs or curled toes were held longer to give individuals the chance to right themselves), (2) the number of chicks in captivity and the number due to hatch (i.e., within 3-4 days), (3) related to this is the amount of available space and resources (generally try to hold 7-10 chicks no longer than 3-4 days together), (4) weather conditions, (5) the number of possible wild females within a study area that will successfully hatch within range of the current domestic cohort, and (6) the number of same age broods on the ground (if only 1 or 2 broods are available will hold chicks fewer days to reduce the possibility that broods are depredated before introductions).

Trapping and Marking of Wild Broods

Once monitoring revealed the successful hatch of a nest all chicks in the brood were captured 1-2 days after hatching. Successfully nesting radio-marked females were located < 1 hour before sunset and chicks captured while the female was brooding. Chicks were captured by hand and held in nylon bird bags for processing. Three chicks within each wild brood were randomly selected and a 1.4 gram, 60-day radio-transmitter was sutured along the dorsal midline between the chick's wings following the procedure of Burkepile et al. (2002). All other chicks within wild broods were subcutaneously injected mid-dorsally just above the wings with an 11 X 2 mm 0.078 gram PIT (passive integrated transponder) tag via a 12-gauge needle (Carver et al. 1999).

Monitoring of Broods

Radio-marked females with radio-marked chicks were monitored daily to determine survival of chicks, location of brood, and acceptance of domestically-hatched chicks into wild broods. Brood position was determined by locating the female and circling to within 25-50 m. Position and relationship (i.e., distance) of radio-marked chicks in

relation to the female was also recorded. In addition, cover type was determined at all locations. Daily observations of broods and chicks were continued for 28 days or until death of chick or loss of entire brood was determined. Attempts were made to find all chicks immediately after becoming separated or missing from broods to determine fate and/ or cause of mortality. After day 28, radio-marked chicks and females were located every 1-3 days depending on logistics.

Capture Techniques for Juvenile Sage-Grouse

Trapping of juvenile sage-grouse occurred between 35-65 days (approximate battery life of chick transmitter) and at approximately 90-120 days of age. At 35-65 days of age chicks were recaptured by locating and following the transmitter at night and using spotlights and long-handled hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Chick transmitters were replaced with a 1.9 gram, 90-day transmitter following the same procedure used for the chicks. Chicks were then recaptured at 90-120 days (at which time they were considered juveniles) using the same methods. Juveniles had the second transmitter removed and replaced with an adult 18 gram, 540-day adult transmitter.

Monitoring of Juveniles and Adults

During the fall and winter, the priority was to locate known (marked with either a radio-transmitter or PIT tag 1-3 days post-hatching) radio-marked juveniles and successful females (>1 chick making it to September 1), as well as any random (caught opportunistically) juveniles. Attempts were made to locate all juveniles and successful females > 2 times per week from August 15 through November 15 and from January 1 through March 1. The remaining radio-marked individuals (broodless females) were tracked opportunistically and as time allowed. In addition, every 2 weeks during the fall and winter flights were taken to locate juveniles who were missing and moved outside of the study areas.

Survival Analyses

Weekly survival rate was estimated with the Kaplan-Meier (KM) product-limit estimator (Kaplan-Meier 1958) modified for staggered entry (Pollock et al. 1989). Sage-grouse chick survival was estimated from hatch or date of adoption to 16 weeks of age, the week before the average age of brood break-up (in 2005 this was during week 17). In addition, because survival is not constant over time but greater during the first 2-3 weeks, survival estimates were divided between early brood (hatch to 4 weeks of age) and late brood (5 to 16 weeks of age). This early brood period represents the most critical time for young chicks and broods because: (1) they are not able to thermoregulate properly until greater than two weeks of age and as such are highly susceptible to weather extremes and exposure (Huwert 2004), and (2) they are not able to properly fly until they are greater than 14-21 days of age and are highly susceptible to predation, especially young broods (S. Differences in survival rates between groups (e.g., study areas, wild- and domestically-hatched) and between years were compared with a Log-rank χ^2 statistic test (Winterstein et al. 2001). Additionally, yearling sage-grouse survival was estimated from hatch in the spring of 2005 to 31 March 2006 for those chicks captured and monitored during this time. Only chicks surviving greater than at least 2 days after suturing of a transmitter or, for domestically-hatched chicks, after introduction and confirmed adoption into wild broods were included in the survival analyses to remove any possible biases that the stress of introduction and suturing of radio-transmitters might have on survival.

RESULTS

Juvenile Yearly Survival and Recruitment

Overall yearling survival of 167 chicks from 31 broods captured and marked in May and June, and monitored through 31 March 2006 in northwest Colorado was 0.2084 (SE = 0.030, 95% CI = 0.1577 – 0.2774) (Figure 2). One-hundred and fifty-five of the juveniles were originally radio-marked as chicks the remaining 12 were PIT-tagged as chicks and radio-marked at either the recapture (approximately 60-days; $n = 10$) or at the fall capture (approximately 100-days; $n = 2$) of age (July and August, or September;

Figure 3). Survival was lowest during May to July corresponding to the first 28-days post-hatch for most chicks ($\hat{S} = 0.4051$, $SE = 0.0343$, 95% CI = 0.3433 – 0.4781). Survival for the entire brood rearing period (May to August) was 0.3528 ($SE = 0.0360$, 95% CI = 0.2890 – 0.4308). In 2005, brood break-up (independence of female from the brood) occurred between August 28 and November 17 and averaged 26.6 days per brood with a range of 14-53 days ($n = 14$). During this brood break-up period and movements into winter flocks and areas (September through November) survival was 0.6393 ($SE = 0.0613$, 95% CI = 0.5333 – 0.7664, $n = 61$), while survival during the winter (December to February) and early spring (March) was 0.9231 ($SE = 0.0421$, 95% CI = 0.8442 – 1.001, $n = 39$). For the entire fall (September to November) through winter (December to March) period juvenile survival was 0.5902 ($SE = 0.0621$, 95% CI = 0.5333 – 0.7664, $n = 61$).

Thirty-five of these known yearlings survived to enter the spring breeding population in 2006. Only 1 yearling, a male, did not return from its wintering area to the study area or within a reasonable distance of the study areas (< 16 km or 10 miles) of its origin to breed. This male was hatched on the west end of the Axial Basin near Juniper Springs II, wintered approximately 5 miles east of Cross Mountain, and was observed with a group of males (non-lekking) during April and May east of Cross Mountain near County Road 85 less than 2 miles from where it wintered. The straight-line distance between the natal nest and the average breeding season locations (locations taken during April and May 2006) for this male was 26.04 km (or 16.3 miles). The remaining 34 yearlings, both male and female, returned to the study areas where they were originally hatched and marked as chicks, however distances from the natal nest and the average breeding season locations for these yearlings varied depending upon the sex of the bird (see Natal Dispersal below).

Spring Trapping and Monitoring of Sage-Grouse

Spring trapping began on 22 March in North Moffat, 24 March in the Axial Basin/Danforth Hills, and on 29 March at Cold Springs Mountain. In North Moffat, 7 new females were caught on 2 leks (Spring Creek and Brushbeat) over 5 nights of trapping (Table 1). The last female was captured at this study area on 8 April. In the Axial Basin/Danforth Hills, 27 new females were caught on 6 leks (primarily on the east half of the

Axial Basin) over 9 nights of trapping. The majority of females were captured in the Axial Basin before 4 April, however the last female was captured on 22 April. At Cold Springs Mountain, 18 new females were added from 2 leks (G Flats and Beaver Basin) over 7 nights of trapping. The last female was captured on 15 April from this study area. In total 52 new females, 30 adults and 22 yearlings have been captured within the study areas during spring trapping in 2006.

During the spring and early summer of 2006, 164 female greater sage-grouse were monitored to determine nesting fate and brood movements (Table 2). In all 3 study areas, more adult females were radio-marked and monitored than yearlings. Half the monitored female yearlings in the Axial Basin/ Danforth Hills and at Cold Springs Mountain were from chicks and juveniles that were radio-marked in 2005 and survived until the spring of 2006 (Table 2). In addition to 22 yearling females from 2005, 13 yearling males (radio-marked as chicks or juveniles in 2006) were also monitored (Table 3).

Sage-grouse Nesting Chronology and Biology

Nesting was confirmed in North Moffat on 11 April (egg laying female with eggs in the nest bowl), in Axial Basin/ Danforth Hills on 16 April (egg laying female with eggs in the nest bowl), and at Cold Springs Mountain on 22 April (incubating female). Hatching dates differed between the study areas. North Moffat hatching dates were the earliest among the areas and occurred during the second week of May, one week before the peak of Axial Basin/ Danforth Hills hatching (Figure 4). The majority of Axial Basin/ Danforth Hills nests hatched between 15 and 28 May, while the majority of Cold Springs Mountain nests hatched during 22 May and 4 June (Figure 4). Nesting chronology was particularly important in relation to egg acquisition and whether eggs were refrigerated and the duration of this period (see below). Because North Moffat was a week ahead of Axial Basin/ Danforth Hills, and 2 weeks ahead of Cold Springs Mountain these eggs were stored longer to synchronize with hatch dates of wild females in these areas.

Sage-grouse Nesting Biology

Ninety-three percent ($n = 113/122$) of females with known nesting status attempted to nest during the spring of 2006 (Table 4). In addition, the Axial Basin had higher rates of females that did not nest and mortalities during the pre-nesting period (Table 4 and 5). One hundred and twenty-three nests (113 first nests and 10 renests) were located and monitored within the Axial Basin/ Danforth Hills and Cold Springs Mountain study areas (Table 4). Additionally, 29 nests (25 first nests and 4 renests) were located and monitored in North Moffat (Table 4). Nest initiation rates appeared lower in the Axial Basin/ Danforth Hills compared to other areas (Table 5). Initial nesting success, renest initiation rates, renest success, and female nesting success varied among sites (Table 5). At Cold Springs Mountain, 9 females originally radio-marked in Colorado spent a large part of the breeding season in either Utah or Wyoming or both (Table 6). Three subsequently nested in Wyoming and 3 in Utah. (Table 6).

Seventy-four nests were depredated (66 initial nests and 8 renests; Table 4). In the majority of cases all or some of the eggs were removed, or damaged such that accurate identification of the cause-specific depredation could not be identified for all nests. However, potential predators observed in the field include black-billed magpies (*Pica hudsonia*), common ravens (*Corvus corax*), ground squirrels (*Spermophilus* spp.), badgers (*Taxidea taxus*), weasels (*Mustella* spp.), red foxes (*Vulpes vulpes*), and coyotes (*Canis latrans*).

Natal Dispersal and Breeding Season Fate of Known Yearlings

Thirty-five known yearlings (i.e., marked as chicks in 2005) were monitored during the 2006 breeding season, 22 females and 13 males (Tables 7 and 8). Among the known yearling females, nest initiation rate was 84.2% (16/19) and female nesting success was 31.3% (5/16) (Table 7). Distances between natal nests and first breeding season nest were calculated as the straight-line distance between each nest pair. In 2006, known yearling females that attempted to nest ($n = 16$) nested within 2.1 ± 0.9 km of their natal nest. Known yearling females that did not nest had their average breeding season

location (average of locations taken in 15 March through 15 May) of 4.0 ± 1.4 km from their natal nest (Table 9).

First nests of yearling females ranged from 0.15 to 11.69 km from their natal nests (Table 7), and 75% of these nests were within 1.6 km of their natal nest (Figure 5). However 2 females, one from the Axial Basin and one from Cold Springs Mountain, did nest ≥ 10 km from their natal nest area. Female C-322-05 moved 10.7 km from her natal nest in Beaver Basin at Cold Springs Mountain to the southwest of Pine Mountain in southern Wyoming, while female A-351-05 moved north-east 11.69 km from her natal nest in west Axial Basin (Juniper Springs II strutting ground).

In general for 2006, natal dispersal of female sage-grouse was highly leptokurtic (skewed left) reflecting high natal fidelity and decreased dispersal away from the natal nest area (Figure 5 and 6). During this time 22.7% (5/22) of the yearling females were depredated, 2 during nesting in May and 3 during pre-nesting in April.

Natal dispersal distances for known yearling males were calculated as the distance between the natal nest and the average breeding season (15 March through 15 May) locations. During the breeding season males were located between 5 – 12 times. In 2006 yearling males averaged 7.7 ± 2.0 km from their natal nest with a range of 1.67 to 26.04 km (Tables 8 and 9). Most of the males were ≥ 3 km (69.2%, $n = 9/13$) and 46.2% ($n = 6/13$) were ≥ 7 km away from their natal nest (Figure 6). For 2006 it appears that yearling males are not strictly philopatric to their natal nest areas in the first year, but range over a wider area during this time. In addition, mortality of yearling males was high during this time. Less than half of the males survived to June 1 (46.2%, $n = 6/13$) and 2 males were found dead on leks. Of the males found on leks one was an obvious avian mortality while the other male showed no signs of external trauma. Necropsy results (Dr. Baeten, pers. comm.) showed congestion around the neck area due to the necklace material of the radio-transmitter, but this could not be confirmed as the cause of death. Only one other male mortality, found during the summer, showed signs of possible mortality due to the placement of the radio-transmitter.

Female Mortalities and Survival

Apparent female survival for the reproductive, brooding, and fall period (1 March through 31 November) was 65.0% ($n = 89/137$). Female survival during this period was slightly higher at Cold Springs Mountain than the Axial Basin [67.2% ($n = 41/61$) and 63.2% ($n = 48/76$). Monthly mortalities were highest during March through May ($n = 17$ or 35.4% of all mortalities) and August through September ($n = 18$ or 37.5% of all mortalities) (Table 10). Twenty-three percent of the mortalities occurred during pre-nesting ($n = 11/48$) and among broodless females (May through August) ($n = 11/48$), while 27% ($n = 13/48$) occurred during the fall (September through October) (Table 10). This was similar to 2005, however twice as many broodless birds were lost over the summer in 2006 compared to 2005 (11 to 5, respectively). Between the 2 study areas proportionally more females were depredated in the Axial Basin during the months of April, May, and August, and among pre-nesting and broodless females compared to Cold Springs Mountain (Table 10). In both study areas more adults were depredated than yearlings, however because of the sample size differences between the 2 groups (see Table 2) the proportions lost were relatively close (35.0% for yearlings ($n = 14/40$) and 36.2% for adults ($n = 34/94$). No radio-marked females from either study area ($n = 137$), or from the North Moffat area ($n = 31$) were harvested during the fall hunting season in 2006.

In addition to the normal range of mortalities for 2006 an additional 5 females and 1 chick that were found dead (either whole or partial) and collected in the field tested positive for West Nile Virus (WNV) (Dr. Baeten, pers. comm.) (Table 11). Two of these females were collected at Cold Springs Mountain during May and June, the remaining 4 were collected during August in the Axial Basin. Two of the WNV deaths were unusual because they were collected on Cold Springs Mountain during the spring at altitudes > 2500 meters (Table 11). Temperatures are cold and no mosquitoes were present in the study area at this time. Both birds collected at Cold Springs Mountain were whole carcasses and showed signs of poor condition (i.e., extremely emaciated). Because these birds were found dead during the spring and not the fall of 2006 it is possible that these individuals contracted WNV during the fall of 2005 and only succumbed to it after

passing through the winter or that these birds contracted it during the spring of 2006 by another vector.

Sage-Grouse Egg Acquisition, Incubation, and Hatching

Forty-four sage-grouse females were designated as egg acquisition females in the 3 study areas, 30 in North Moffat, 10 in the Axial Basin/ Danforth Hills, and 4 at Cold Springs Mountain. Eggs were subsequently collected from 20 females (14 adults and 6 yearlings) from the 3 areas (11 from North Moffat, 4 from Axial Basin/Danforth Hills, and 5 from Cold Springs Mountain). One hundred two sage-grouse eggs were collected during the spring of 2006 (Table 12). The first egg was collected on 11 April and the last egg was collected on 10 May.

In total 76 “good” eggs (eggs that were collected from laying or incubating females) were collected from 17 females for an average of 4.47 eggs taken per female. Only 2 females subsequently abandoned after removal of eggs and replacement with artificial eggs. The remaining 26 eggs were collected from nests in which the female had been killed or from abandonment of the nest by the female. In addition, 4 females were flushed off their nest (3 during laying and 1 during incubation) and all of their eggs removed from the nest.

The majority of eggs in 2005 and 2006 were collected from laying and incubating females with the majority coming from laying females (Table 12). Laid eggs were stored an average 7.8 days (range 5 – 11) before being placed in the incubator (storage length reflects the amount of time needed to synchronize the hatching of North Moffat eggs with wild broods in the Axial Basin/ Danforth Hills; see above). In 2006, the hatching rate of egg acquisition (EA) or “good” eggs was 64.5% ($n = 49/76$), lower than in 2004 and 2005 (Table 12). Similarly, the hatching rate of stored eggs was lower in 2006 compared to 2005 (Table 12). The number of eggs showing no signs of development after being placed in the incubator was higher compared to the previous 2 years (Table 12).

In 2005 and 2006, hatching rates were higher for eggs collected from incubating females compared to laying females (Table 13). This possibly reflects the decreased hatchability of refrigerated eggs (i.e., the majority of which are eggs collected during laying). Combined (2005 and 2006) hatching success appears greater for eggs collected

from incubating females compared to laying females (Table 13). Over the 2 years more chicks were successfully hatched and introduced into wild broods from eggs taken from incubating females compared to eggs taken from laying females whose eggs had been refrigerated (Table 14) despite more eggs being collected from laying compared to incubating females (Table 12 and 13).

Domestically-raised Chicks

In 2006, 55 chicks were hatched in captivity, and 37 of these chicks (67.3%) were subsequently released into the wild (Table 15). Compared to previous years the number of chicks with external abnormalities (i.e., splayed legs, curly toes) and those that needed to be euthanized appeared lower, however the number of chicks dying in captivity was higher (Table 15). Fourteen chicks, 7 in the ≤ 4 days in captivity and 7 in the ≥ 4 days in captivity, died in 2006 of unknown causes. These chicks did not differ significantly in initial weight (weight taken directly after hatching) from the other successfully hatched chicks (27.2 compared to 29.4 grams respectively; $t_{\text{obs}} = 2.04$, $df = 17$, $P = 0.058$) and did not show external signs of problems (i.e., splayed legs). Additionally, 64.3% (9/14) of these chicks were from refrigerated eggs and 7 of 14 showed weight gains of less than 1 g/day during $>$ than 3 days in captivity.

Twenty-one domestically-hatched chicks were given to 8 broods in the Axial Basin/Danforth Hills, and 14 were given to 6 broods at Cold Springs Mountain. The two remaining chicks died to human error during transport to release in the Danforth Hills. Adoption rate was 85.7% (30/35) through the first day. Five chicks (1 in the Axial Basin and 4 from Cold Springs Mountain) were found dead the morning after the introduction due to exposure and probably the stress of the introduction. These chicks were removed from any further survival analysis.

During 2005 and 2006, 103 domestically-hatched chicks were raised in captivity to either ≤ 4 day (Treatment 1; $n = 66$) or ≥ 4 days (Treatment 2; $n = 37$). Table 16 provides a summary of domestically-hatched chick weights (both initial and final) and weight gains (average grams per day) for each treatment depending on whether the chick survived to introduction and adoption into a wild brood (success) or died before

introduction and adoption (failure). Successful domestically-hatched chicks were significantly heavier and had higher average daily weight gains than chicks that failed for both treatment 1 [33.6 g compared to 30.1 g ($t_{\text{obs}} = 2.72$, $df = 25$, $P = 0.0117$) and 0.9 g/day compared to 0.4 g/day ($t_{\text{obs}} = 2.08$, $df = 34$, $P = 0.0468$)] and treatment 2 [44.9 g compared to 33.1 g ($t_{\text{obs}} = 4.92$, $df = 35$, $P < 0.0001$) and 2.2 g/day compared to 0.9 g/day ($t_{\text{obs}} = 3.83$, $df = 26$, $P = 0.0007$)] (Table 16).

In general, successful domestically-hatched chicks raised to approximately 4 days should be heavier than 33 grams and show at least a 0.8-1.0 gm gain in weight over the time in captivity, while chicks raised longer than 4 days (5 – 9) should be 42-43 grams or heavier and have an average daily weight gain of 2.0 or higher for the days in captivity (Table 16). The chicks that failed within each treatment had significantly lower final weights and average daily weight gains than the chicks that were ultimately introduced into and adopted by wild broods (Table 16).

2006 Greater Sage-grouse Brood and Chick Captures

Forty-eight broods were produced from the 113 nests that were initiated within the Axial Basin and Cold Springs Mountain study areas during the spring of 2006 (Table 17). One of these broods was promptly depredated, so only 47 were monitored with radio-marked chicks. One hundred and seventy-nine chicks (144 wild-hatched and 35 domestically-hatched) were radio-marked 1-3 days post-hatch and monitored (Table 17). In addition, 153 non-radio-marked chicks were PIT tagged on the 2 study areas at 1-3 days post-hatching, and 15 of these were subsequently caught and radio-marked during the recapture at approximately 50-days of age or during captures of juveniles in September (Table 17). In total 194 hatch-year grouse were radio-marked and tracked during the summer and fall of 2006. One-hundred chicks were radio-marked in the Axial Basin/ Danforth Hills and 94 in the Cold Springs Mountain study areas (Table 17).

From the 144 radio-marked chicks captured 1-3 days post-hatch, 61 survived to the second recapture and re-radio-marking. Re-radio-marking occurred on average at 42.8 days of age which was approximately 9-10 days sooner than in 2005. Earlier recaptures were necessary to ensure that chicks were captured before transmitters failed. During this stage, from hatch to approximately 43-days post-hatch, the fate of 55, or 29.1% of the

total chicks radio-marked ($n = 179$) could not be determined (30 in the Axial Basin and 25 at Cold Springs Mountain), more than double the number from last year (in 2005, only 21 chicks transmitters, or 13.1% could not be accounted for) (Table 17). Censored chicks included those with dropped transmitters (3), human error (2), radio-failure (16 confirmed), and 34 that were missing (Table 17). The majority of radio-failure and missing chicks occurred during the first four weeks post-hatch (84.6%). Because broods were tracked every day for the first 28 days, the most likely reason for missing chicks is due either to predators destroying transmitters or removing them from the study area, or premature battery failure in refurbished chick transmitters.

In 2006, during the second recapture the majority of chicks were caught between July 1 and July 11 in the Axial Basin/ Danforth Hills and between July 8 and July 19 at Cold Springs Mountain. Eighty-four, approximately 45-day-old sage-grouse were radio-marked during this stage of capture, 44 from Axial Basin/ Danforth Hills and 40 from Cold Springs Mountain study areas. Thirty chicks from Axial Basin/ Danforth Hills and 31 from Cold Springs Mountain were re-radio-marked (i.e., those originally radio-marked 1-3 days post-hatch) during this time period. The chicks re-radio-marked in 2006 were recaptured approximately 6-10 days earlier than last year due to premature battery failure. In addition to these 61 re-radio-marked chicks, 10 chicks PIT-tagged at 1-3 days post-hatch (5 from the Axial Basin/ Danforth Hills and 5 from Cold Springs Mountain) and 16 unknown random-juveniles (9 from the Axial Basin/ Danforth Hills and 4 from Cold Springs Mountain) were radio-marked at this stage (Table 17). Random chicks were those individuals captured while attempting to capture known broods that did not have a PIT tag or signs of previously being radio-marked as chicks. These random chicks could possibly be unmarked related brood-mates, adopted unrelated brood-mates, or individuals from other broods that were using the same roosting areas.

2006 Greater Sage-grouse Brood and Chick Survival

In 2006, broods had a survival rate 46.8% (SE = 7.0%, 95% CI = 35.2% – 62.57%, $n = 47$) and radio-marked chicks (both wild-hatched and domestically-hatched combined) had a survival rate of 37.4% (SE = 4.9%, 95% CI = 29.0% – 48.2%, $n = 175$) to 16 weeks of age (Table 17 and Figure 7). Among wild-hatched chicks, there were no differences in

survival rates between Axial Basin and Cold Springs Mountain from hatch to 16 weeks of age (38.5% and 41.3%, respectively; Log-rank $\chi^2_1 = 0.01$, $P = 0.934$) (Table 17 and Figure 8). In both the Axial Basin and Cold Springs Mountain chick survival was lowest during weeks 1 and 2 compared to any other week.

Compared to wild-hatched chicks, domestically-hatched chicks had significantly lower survival from hatch to 16 weeks of age [38.5% (SE = 5.4%, 95% CI = 29.3% – 50.7%, $n = 145$) and 30.4% (SE = 10.4%, 95% CI = 15.9% – 58.2%, $n = 30$), respectively; Log-rank $\chi^2_1 = 5.78$, $P = 0.0162$] (Figure 9). However, this difference was greatest during the first 4 weeks [72.8% (SE = 4.4%, 95% CI = 64.7% – 81.8%, $n = 145$) and 39.4% (SE = 9.2%, 95% CI = 25.0% – 62.0%, $n = 30$), respectively; Log-rank $\chi^2_1 = 13.68$, $P = 0.0162$] (Figure 9). Only chicks surviving greater than at least 2 days after introduction and confirmed adoption were included in the survival analyses to remove any possible biases that the stress of introduction and suturing of radio-transmitters might have on survival. In 2006, 5 chicks were removed from further analysis due to mortalities within the first 48 hours of introduction (1 from the Axial Basin and 4 from Cold Springs Mountain). Similar to wild-hatched chicks, domestically-hatched chicks had the lowest survival during the first 4 weeks; however losses at this time were substantially higher among the domestically-hatched chicks (Figure 9).

Nineteen domestically-hatched chicks were successfully introduced into wild broods in the Axial Basin and 11 were introduced at Cold Springs Mountain. No domestically-hatched chicks survived past 39 days (7 weeks) within the Cold Springs Mountain study area (Figure 10). Survival of domestically-hatched chicks in the Axial Basin to 16 weeks of age was similar to that of wild-hatched chicks [36.1% (SE = 11.8%, 95% CI = 19.4% – 67.3%, $n = 19$) and 38.5% (SE = 8.7%, 95% CI = 24.8% – 59.6%, $n = 69$), respectively; Log-rank $\chi^2_1 = 1.18$, $P = 0.2765$] (Figure 11). However, during the first 4 weeks survival was significantly lower for domestically-hatched chicks weeks (Log-rank $\chi^2_1 = 5.84$, $P = 0.0157$) (Figure 11).

The 35 domestically-hatched chicks were categorized based on their length of time in captivity as either treatment 1 (less than or equal to 4 days) or treatment 2 (greater than or equal to 5 days). Twenty-three chicks were categorized as treatment 1 and 7 chicks as treatment 2 after excluding the 5 chicks removed from further analysis due to mortalities

within the first 48 hours after introduction (Figure 12). Differences in sample sizes between the 2 treatments reflects logistical issues in holding chicks for extended periods (e.g., number of chicks in captivity at 1 time, unforeseen deaths in captivity; but see below), as well as loss of broods in each of the study areas. Only 3 of the 21 chicks introduced into the Axial Basin were categorized as treatment 1, while 7 of the 11 chicks introduced at Cold Springs Mountain were categorized as treatment 2. No domestically-hatched chick within treatment 2 survived past 39 days (7 weeks), while chicks within treatment 1 had similar survival rates to wild-hatched chicks (35.8% and 38.5%, respectively; Log-rank $\chi^2_1 = 1.85$, $P = 0.1564$) (Figure 12). This difference between treatments is similar to that between domestically-hatched chicks in the 2 study areas and thus may be a reflection of the increased impacts (i.e., lower survival) incurred by chicks introduced into Cold Springs Mountain and not an actual treatment effect.

Greater Sage-Grouse Chick and Brood Survival Comparisons between Years

There was no difference in survival rates between broods radio-marked and monitored in 2005 and 2006 in northwestern Colorado to 16 weeks of age [50.0% (SE = 8.8%, 95% CI = 35.5% – 70.5%, $n = 32$) and 46.8% (SE = 7.0%, 95% CI = 35.0% – 62.6%, $n = 47$), respectively; Log-rank $\chi^2_1 = 0.01$, $P = 0.9222$] (Figure 13). Similar to broods, radio-marked chick (both wild-hatched and domestically-hatched combined) survival rates did not differ between 2005 and 2006 to 16 weeks of age in northwestern Colorado [37.4% (SE = 4.7%, 95% CI = 29.7% – 47.2%, $n = 147$) and 37.4% (SE = 4.3%, 95% CI = 29.0% – 48.2%, $n = 175$), respectively; Log-rank $\chi^2_1 = 1.27$, $P = 0.5125$] (Figure 14).

Among wild-hatched chicks there were no differences in survival rates to 16 weeks of age between 2005 and 2006 (Log-rank $\chi^2_1 = 1.07$, $P = 0.3003$), however the pattern of chick mortalities varied between the two years (Figure 15). In 2005 chick survival rates were lower during the first 4 weeks compared to 2006 age [58.1% (SE = 4.5%, 95% CI = 49.9% – 67.7%, $n = 121$) and 72.8% (SE = 4.4%, 95% CI = 64.7% – 81.8%, $n = 145$), respectively; Log-rank $\chi^2_1 = 4.77$, $P = 0.0289$] (Figure 15). The differences in wild-hatched chick survival rates during the first 4 weeks was most likely due to the differences in weather conditions between the two years. Weather conditions during May and June of 2005 were wetter and colder, especially at Cold Springs Mountain compared

to 2006, while during 2006 conditions were much drier latter in the summer compared to 2005 (i.e., general observation). These differences in weather conditions during the early and late brood rearing periods (weeks 1-4 and weeks 5-16) could account for the yearly differences observed in chick survival patterns.

Wild-hatched chick survival rates did not differ statistically between years in the Axial Basin to 16 weeks of age [50.1% (SE = 6.9%, 95% CI = 38.2% – 65.6%, $n = 65$) and 38.5% (SE = 8.7%, 95% CI = 24.8% – 59.6%, $n = 69$), respectively; Log-rank $\chi^2_1 = 0.11$, $P = 0.7410$] (Figure 16). A difference in survival rates to 16 weeks of age was observed for wild-hatched chicks between years at the Cold Springs Mountain study area [25.0% (SE = 6.5%, 95% CI = 15.1% – 41.4%, $n = 56$) and 41.3% (SE = 7.3%, 95% CI = 29.4% – 58.2%, $n = 75$), respectively; Log-rank $\chi^2_1 = 5.13$, $P = 0.0235$] (Figure 17).

Among the domestically-hatched chicks survival rates did not differ between years to 16 weeks of age [30.6% (SE = 9.6%, 95% CI = 16.8% – 55.9%, $n = 26$) and 30.4% (SE = 10.4%, 95% CI = 15.9% – 58.2%, $n = 30$), respectively; Log-rank $\chi^2_1 = 0.50$, $P = 0.4793$] (Figure 18). Among the domestically-hatched chicks categorized as treatment 1 (≤ 4 days in captivity) survival rates were comparable between years to 16 weeks of age (Log-rank $\chi^2_1 = 0.68$, $P = 0.4180$) (Figure 19). Among the domestically-hatched chicks categorized as treatment 2 (≥ 5 days in captivity) only those in 2005 survived greater than 39 days (week 7) (Figure 20). Low sample sizes between years within in treatment 2 ($n = 13$ in 2005 and $n = 7$ in 2006) prohibited the testing of differences in survival estimates.

Northwest Colorado Greater Sage-Grouse Brood and Chick Survival 2005-2006

Over the first 2 years of this study a total of 79 greater sage-grouse broods have been radio-marked and monitored in Moffat County (40 in the Axial Basin and 39 at Cold Springs Mountain) (Table 18). Brood survival between the Axial Basin and Cold Springs Mountain study areas did not differ over the 2 years combined (Log-rank $\chi^2_1 = 0.37$, $P = 0.5429$) and yielded a combined estimated brood survival rate of 48.1% (Figure 21). In addition, 322 greater sage-grouse chicks (266 wild-hatched and 56 domestically-hatched) have been radio-marked and monitored during this time (Table 18). Overall chick survival (both wild- and domestically-hatched combined) to 16 weeks of age did not

differ between the Axial Basin and Cold Springs Mountain study areas over the 2 years combined (Log-rank $\chi^2_1 = 1.73$, $P = 0.1884$) and yielded a combined estimated chick survival rate of 38.8% (Figure 22). Similarly, among the wild-hatched chicks survival to 16 weeks of age did not differ between the 2 study areas over the 2 years [46.3% (SE = 5.5%, 95% CI = 36.7% – 58.4%, $n = 134$) and 34.7% (SE = 5.0%, 95% CI = 26.1% – 46.0%, $n = 132$), respectively; Log-rank $\chi^2_1 = 2.52$, $P = 0.1125$] (Figure 23). Even though there was a year effect between 2005 and 2006 wild-hatched chick survival rates to 16 weeks of age at Cold Springs Mountain, there was still no significant difference in survival between the 2 study areas over the 2 years combined (Figure 23).

The survival rate estimate to 16 weeks of age was significantly different between wild- and domestically-hatched chicks when the years were combined years [39.4% (SE = 3.7%, 95% CI = 32.8% – 47.4%, $n = 266$) and 29.6% (SE = 6.9%, 95% CI = 18.9% – 46.4%, $n = 56$), respectively; Log-rank $\chi^2_1 = 4.78$, $P = 0.0287$] (Figure 24), even though in 2005 no difference was detected while in 2006 there was. During the first 4 weeks post-introduction survival rates were significantly different between domestically- and wild-hatched chicks ((Log-rank $\chi^2_1 = 8.13$, $P = 0.0044$), however after the first 4 weeks survival rates were similar between the 2 groups to 16 weeks of age (Log-rank $\chi^2_1 = 0.13$, $P = 0.7202$).

Survival rates of domestically-hatched chicks to 4 weeks and to 16 weeks of age did not differ between the 2 treatments (Log-rank $\chi^2_1 = 3.77$, $P = 0.0521$ and Log-rank $\chi^2_1 = 2.92$, $P = 0.0875$, respectively), however once again sample sizes were low for comparisons between treatments (Figure 25). Low sample sizes within treatment precluded any further analysis for the period between week 5 to week 16 ($n = 17$ for treatment 1 and $n = 5$ for treatment 2).

Treatment survival rates differed when compared individually to wild-hatched-chick survival rates. Survival rate estimates did not differ to 4 weeks or 16 weeks of age between domestically-hatched chicks in treatment 1 (57.0% and 35.7%) and wild-hatched chicks (65.7% and 39.4%) (Log-rank $\chi^2_1 = 1.21$, $P = 0.2716$ and Log-rank $\chi^2_1 = 0.61$, $P = 0.4360$, respectively) (Figure 26). Survival rate estimates differed between domestically-hatched chicks in treatment 2 and wild-hatched chicks to 4 weeks (25.0% and 65.7%, respectively; Log-rank $\chi^2_1 = 14.92$, $P = 0.0002$) and to 16 weeks (20.0% and 39.4%,

respectively; Log-rank $\chi^2_1 = 10.67$, $P = 0.0019$) of age, however the sample size within treatment 2 was very low for these comparisons ($n = 20$ compared to $n = 266$). In the 2 years of this study, 24 of the 79 wild radio-marked broods have had domestically-hatched chicks introduced and adopted into them. Survival rates to 16 weeks of age did not differ between wild brood and wild broods with adopted domestically-hatched chicks (Log-rank $\chi^2_1 = 0.02$, $P = 0.8944$) (Figure 28).

2006 Fall Captures of Juvenile Greater Sage-Grouse

During September and the first 2 weeks of October, 55 juvenile sage-grouse were captured and radio-marked (Table 19). Thirty-four of these, 19 from Axial Basin/Danforth Hills and 15 from Cold Springs Mountain were from the original cohort radio-marked or PIT-tagged at 1-3 days post-hatch (Table 19). In addition, 16 unknown random juveniles, 5 from the Axial Basin and 11 from Cold Springs Mountain were added. At this age (> 100 days-old) the sex of the juveniles can be determined. Of the 55 juveniles captured 39 were females and 16 were males with the ratios being roughly equivocal between the two study areas (Table 19).

Chick and Juvenile Capture Weights

The weights of chicks and juveniles were taken for all known (marked with chick transmitter or PIT tag at 1-3 days post-hatching) and random (unknown parentage and origin) individuals captured at 1-3 days post-hatching, during the second recapture (32-69 days of age), and during the fall capture of juveniles (Table 20). Domestically-hatched chicks were initially weighed less than 2 hours after hatching before placement into a brooder. The hatch weights of domestically-hatched chicks differed between 2005 and 2006 with chicks in 2006 being lighter on average than chicks in 2005 ($t_{\text{obs}} = 2.65$, $df = 99$, $P = 0.0094$). Because wild-hatched chicks were captured on average at ages greater than 1 day (range of 1 to 7) their initial weights were not tested for differences with wild-hatched chicks. In addition, the second recapture weights were not tested between years due to differences in age of capture.

In 2006, chicks were caught during the second recapture approximately 6-12 days earlier due to weak signals and impending battery failure (Table 20). Among the wild-

hatched chicks no differences were detected between years within sites or between site for the initial capture and for fall captures of males and females ($P > 0.05$) (Table 20). For the years taken together, no differences were detected between sites for initial chick weights, weights during the second recapture, or for fall weights of males and females ($P > 0.05$). In addition, domestically-hatched chicks were similar in weight to wild-hatched chicks at the second recapture ($P > 0.05$) and during the fall captures of males and females ($P > 0.05$), although sample sizes were small among the domestically-hatched individuals especially among the juveniles (Table 20). Among the juveniles caught during the fall, a significant difference in weight was detected between the sexes with no overlap occurring ($P < 0.01$). At approximately 100 days of age males were on average 460.7 grams heavier than females.

SUMMARY

During the spring of 2006, 35 known juveniles (birds originally marked as chicks 1-3 days post-hatching in 2005) survived to enter the breeding population as yearlings. Survival from hatch to yearling status was estimated as 0.2084 (95% CI = 0.1577 – 0.2774). Recruitment was high for both males and females returning to the study area of their origin, however natal dispersal movements varied between the sexes. Only 1 yearling, a male, did not return to its natal study area but moved 26.0 km. Contrary to what was predicted, females tended to be more philopatric to their natal area than males during this first year. On average, spring locations of females were closer to their natal lek than males (2.6 km to 7.7 km, respectively). In addition 75% of the nests initiated by known yearling females were within 1.6 km (or 1 mile) of their natal nest. Also during this time, mortality rates for yearling males were substantially higher than yearling females. Only 46.2% (6/13) of the yearling males survived to June 1 compared to 77.3% (17/22) yearling females.

In 2006, female nesting success was higher in Moffat County than in 2005 (42.5% and 35.6%, respectively) especially at Cold Springs Mountain (44.8% and 32.5%, respectively). Peak hatching dates varied between sites, however in 2006 peak dates were a week later in the Axial Basin and a week earlier at Cold Springs Mountain. Female survival was lower during the breeding season (primarily during pre-nesting in

March and April), however a larger proportion occurred during May through August in 2006. Six sage-grouse were confirmed to have died from West Nile virus during 2006, 2 at Cold Springs Mountain and 3 in the Axial Basin. Surprisingly, the 2 confirmed deaths at Cold Springs Mountain were found in late May and early June (i.e., whole carcasses) at altitudes above 2500 meters, well before any mosquitoes had emerged. The 3 deaths in the Axial Basin were found in August.

Brood survival in 2006 was similar to 2005 with 46.8% of the broods surviving to 16 weeks. Wild-chick survival, on the other hand, was greater in 2006 than 2005 to 4 weeks of age (72.8% and 58.1%), but did not differ to 16 weeks of age (38.5% and 40.0%). Among wild-hatched chicks there were no differences in survival rates between the Axial Basin and Cold Springs at 4 weeks (77.0% and 68.6%) and at 16 weeks (38.5% and 41.3%, respectively) of age in 2006. However, in 2005 there was a difference with Cold Springs Mountain wild-hatched chicks having lower survival to 4 weeks (51.6% and 68.9%, respectively). There were no differences in survival rates to 4 weeks and 16 weeks in the Axial Basin for either year. For the years combined the survival rates were not significantly different between the 2 study areas despite the year effect at Cold Spring Mountain. Combined, the overall survival rate of wild-hatched chicks in Moffat County, Colorado to 4 weeks is 65.7% and to 16 weeks is 39.4%. Within both study areas and within each year the highest mortality rates for wild-hatched chicks were during the first 4 weeks, especially the first 2 weeks.

Domestically-Hatched Chicks: Egg Acquisition and Captive Rearing

In 2005 and 2006 eggs were collected primarily from laying and incubating females. Generally, collecting eggs from laying females required more effort, but was preferred. Once females have localized in an area they must be located twice daily to determine the location of the nest before the onset of incubation. When, the nest of a laying female has between 2-5 eggs, half the eggs can be removed and replaced with artificial eggs, without compromising the nesting attempt of the female. Advantages of this are that eggs can be collected immediately, removing the risk that the nest could be depredated as more time passed, and the female will continue to incubate the partial clutch. Additionally, eggs that are collected before the onset of incubation can be stored in a refrigerator for a short

period of time, thus allowing time for synchronizing adoptions with female grouse in other study areas that might have different nest initiation dates. The main disadvantage of this method is that while following a female the nest may not be found before the female starts incubating. In addition, more time must be spent per female to find the nest before incubation, and thus fewer females can be monitored than if eggs were taken during incubation. The other method is to follow a female less intensely every 2-3 days until incubation is determined and then to bump the female off the nest (e.g., within 1-3 of the start of incubation) and collect all the eggs. The main advantage to this method is that more females can be monitored and thus more eggs potentially collected. The 2 main disadvantages are that the female may not renest, and that the eggs must immediately be placed in a portable incubator or kept warm and taken directly to and placed in a permanent incubator.

For 2005 and 2006, 84 eggs were collected from laying females while 52 were collected from incubating females. However, despite lower number of incubated eggs collected over 50% of all chicks that were successfully introduced into wild broods were from incubating females. In addition, the percent hatched, as well as percent surviving to introduction into wild broods were higher from eggs collected from incubating females compared to laying females. The most likely reason for this difference is that the majority of eggs collected from laying females were placed in a refrigerator for 5-11 days before being placed in the incubator to synchronize hatching with wild broods. In both 2005 and 2006 storage lengths were on average for 8 days resulting in hatching success rates of 50.0% and 56.3%, respectively. Huwer (2004) in a study on domestically-reared sage-grouse found evidence for decreased hatchability as egg storage length increases. If possible eggs should not be stored or stored for longer than 5 days

In 2005 and 2006, 66.7% and 67.3%, respectively of the successfully hatched chicks survived to introduction into wild broods. Twenty-two percent of all deaths in captivity were chicks that needed to be euthanized due to extreme external deformities, such as splayed legs, curled toes, seizures, or curved backs that did not correct with time. In 2006 only 3 chicks of the 19 that died were due to external deformities. Temperatures of the incubator and hatcher should be monitored 4-6 times per day and humidity monitored every other day. Proper incubator and hatcher temperatures and humidity is extremely

important to minimize the number of deformities such as splayed legs and curled toes (Harvey 1993).

The majority of deaths in captivity for the 2 years were due to unknown causes including internal abnormalities such as digestive problems, that cannot be detected externally, but is more likely a combination of inadequate nutrition, poor thermoregulation abilities, and stress during movement and handling (i.e., chicks are moved between inside and outside rearing pens and weighed in the morning and in the evening).

For the 2 years combined hatch weight (or birth weight) did not determine the success of a domestically-hatched chick. During 2005 and 2006, 103 domestically-hatched chicks were raised in captivity to either ≤ 4 day (Treatment 1; $n = 66$) or ≥ 4 days (Treatment 2; $n = 37$). Within each treatment the final weight and weight gain was greater for chicks that were successfully introduced and those that failed before introduction into wild broods. In general, successful domestically-hatched chicks raised to approximately 4 days should be heavier than 33 grams and show at least a 0.8-1.0 gain in weight over the time in captivity, while chicks raised 5 – 9 days should be 42-43 grams or heavier and have an average daily weight gain of 2.0 or higher for the days in captivity.

Domestically-Hatched Chick Survival

In 2005 the survival rate of domestically- and wild-hatched chicks did not differ to 4 and 16 weeks of age. However, in 2006 to 4 weeks and to 16 weeks domestically-hatched chicks had lower survival compared to wild-hatched chicks. For the years combined survival was significantly lower during the first 4 weeks post-hatch compared to wild-chicks, although survival rates after this period (week 5 to 12) were comparable. When survival was compared between treatments for both 2005 and 2006 no differences were detected to 4 weeks and 16 weeks of age. Domestically-hatched chicks in treatment 1 (≤ 4 days in captivity) and wild-hatched chicks had similar survival rates to 4 weeks and to 16 weeks of age. A difference was detected in survival rate estimates between domestically-hatched chicks in treatment 2 (≥ 5 days) and wild-hatched chicks to 4 weeks and to 16 weeks of age, however the sample size within treatment 2 was very low for these comparisons ($n = 20$ compared to $n = 266$).

Because there was no difference detected between domestically-hatched chicks in treatment 1 and wild-hatched chicks to 4 weeks of age and due to limitation in sample sizes for comparisons between treatments and between treatments and wild-hatched chicks a *post hoc* power analysis needs to be conducted to detect a specified effect, or to calculate the minimum detectable effect size for a given power (Quin and Keough 2002). A preliminary power analyses was performed in SAS using the power procedure for rank tests to compare survival curves. Analyses were used to perform comparisons of 2 survival distributions (i.e., domestically- and wild-hatched and domestically-hatched within treatments) assuming proportional hazards. When $\alpha = 0.10$ and power = 0.80 and the ratio of the hazards for the 2 groups is 1.5 a sample size of between 58 and 73 radio-marked individuals in each group would be required. This is within the range of this study (i.e., allocated transmitter) for testing the survival rates between domestically-hatched and wild-hatched chicks to 4 weeks of age within years, although these sample sizes have not been obtained in the field. To perform comparisons between treatments or for testing between treatments and wild-hatched chicks the same sample sizes would need to be doubled.

ACKNOWLEDGMENTS

I wish thank Dr. Kerry Reese at the University of Idaho and Dr. Tony Apa at the Colorado Division of Wildlife for all their work, effort, input, and patience that they have provided me and this project over the last 2 years. I wish to thank and acknowledge all those individuals and organizations that have provided assistance and funding. I would like to acknowledge financial, logistic, and technical support of the following agencies and organization without which this project would not be possible Colorado Division of Wildlife, University of Idaho, Rio Tinto Energy (Colowyo Coal Company), and the National Fish and Wildlife Foundation. In particular I would like to thank and acknowledge the following landowners for their continued support and interest: the Vermillion Ranch (the Dickinson Family), John Raftopoulos, Simpson Ranch, the Moore Family, Ken Bekkedahl, the Cook Family, Seely Land and Livestock Company, Cross Mountain Ranch, Deakins Ranch, Nick and Ann Charchalis, Visintainer Sheep Company (Dean Visintainer) Brannan Brothers, Leonne Earl, Kourlis Ranch, Colowyo Coal Company, and the Moffat County Grazing Board and State Land Board.

In addition, I wish to acknowledge the hard work and dedication of the following field technicians over past 2 years: Lief Wiechman, Kent Rider, Kristy Howe, Brandon Miller, Adam Gmyrek, , Kathleen Tadvick, Chris Yarbrough, Aimee Weise, Natasha Gruber, Phillip Street, Nick Gould, Bryan Voelker, Jennie Sinclair, Mackenzie Shardlow, and Matt Christensen.

LITERATURE CITED

- Blundell, G. M., M. B. David, P. Groves, R. T. Bowyers, and E. Geffen. 2002. Characteristics of sex-biased dispersal and gene flow in coastal river otters: implications for natural recolonization of extirpated populations. *Molecular Ecology* 11:289-303.
- Braun, C. E. 1998. Sage grouse declines in western North America: what are the problems? *Proceedings of the Western Association of State Fish and Wildlife Agencies* 78:139-156.
- Braun, C. E. 1995. Distribution and status of sage grouse in Colorado. *Prairie Naturalist* 27:1-9.
- Braun, C. E., and D. M. Hoffman. 1979. Vulnerability and population characteristics of sage grouse in Moffat County. Job Progress report. W-37-R-32, Work Plan 3, Job. 11. Colorado Division of Wildlife, Fort Collins 163-199.
- Braun, C. E., T. Britt, and R. O. Wallestad. 1977. Guidelines for maintenance of sage grouse habitats. *Wildlife Society Bulletin* 5:99-106.
- Burkepile, N. A., J. W. Connelly, D. W. Stanley, and K. P. Reese. 2002. Attachment of radiotransmitters to one-day-old Sage Grouse chicks. *Wildlife Society Bulletin*. 30: 93-96.
- Carver, A. V., L. W. Burger, L. A. Brennan. 1999. Passive integrated transponders and patagial tag markers for northern bobwhite chicks. *Journal of Wildlife Management* 63(1):162-166.
- Clarke, A. L., B.-E. Saether, and E. Roskaft. 1997. Sex biases in avian dispersal: a reappraisal. *Oikos* 79:429-438.
- Clobert, J., J. O. Wolff, J. D. Nichols, E. Danchin, and A.A. Dhondt. 2003. Introduction. *In* *Dispersal*, J. Clobert, E. Danchin, A. A. Dhondt, and J. D. Nichols, editors. Oxford University Press.
- Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. Monitoring of Greater Sage-Grouse habitats and populations University of Idaho, College of Natural Resources Experimental Station, Station Bulletin. 80.
- Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines for management of sage grouse populations and habitat. *Wildlife Society Bulletin* 28:967-985.
- Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in Western North America. *Wildlife Biology* 3:229.

- Connelly, J. W., R. A. Fischer, A. D. Apa, K. P. Reese, and W. L. Wakkinen. 1993. Renesting by Sage Grouse in southeastern Idaho. *Condor* 95:1041-1043
- Crawford, J. A., R. A. Olson, N. E. West, J. C. Moseley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of Sage-Grouse and Sage-Grouse habitat. *Journal of Range Management* 57:2-19.
- Dalke, P. D., D. B. Pyrah, D. C. Stanton, J. E. Crawford, and E. F. Schlatterer. 1963. Ecology, productivity, and management of Sage Grouse in Idaho. *Journal of Wildlife Management* 27:811-841.
- Dieckmann, U., B. O'Hara, and W. Weisser. 1999. The evolutionary ecology of dispersal. *Trends in Ecology and Evolution* 14:88-90.
- Dobkin, D. S. 1995. Management and conservation of sage-grouse, denominative species for the ecological health of shrubsteppe ecosystems. High Desert Ecological Research Institute, Bend, Oregon, USA.
- Dunn, P. O., and C. E. Braun. 1985. Natal dispersal and lek fidelity of sage-grouse. *Auk* 102:621-627.
- Dunn, P. O., and C. E. Braun. 1986. Late summer-spring movements of juvenile sage-grouse. *Wilson Bulletin* 98:83-92.
- Fahrig, L., and G. Merriam. 1994. Conservation of fragmented populations. *Conservation Biology* 8:50-59.
- George, S. L. 1983. The required size and length of a phase III clinical trial. Pages 287-310 in M. E. Buyse, M. H. Staquet, and R. J. Sylvester, editors. *Cancer clinical trials*. Oxford University Press, New York, New York, USA.
- Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. *Wildlife Society Bulletin* 10:224-231.
- Greenwood, P. J. 1980. Mating systems, philopatry and dispersal in birds and mammals. *Animal Behavior* 28:1140-1162.
- Greenwood, P. J., and P. H. Harvey. 1982. Natal and breeding dispersal in birds. *Annual Review of Ecology and Systematics* 13:1-21.
- Halfmann, D. A. 2002. Natal dispersal of greater prairie-chicken in Wisconsin. Thesis, University of Wisconsin, Stevens Point, Wisconsin, USA.
- Harvey, R. L. 1993. *Practical incubation*. Revised edition. Hancock House, Blaine, Washington, USA.

- Hausleitner, D. 2003. Population dynamics, habitat use, and movements of Greater Sage-Grouse in Moffat County, Colorado. Thesis, University of Idaho, Moscow, Idaho, USA.
- Howard, W. E. 1960. Innate and environmental dispersal of individual vertebrates. *American Midland Naturalist* 63:152-161.
- Huwer, S.L. 2004. Evaluating greater sage-grouse brood habitat using human-imprinted chicks. Thesis, Colorado State University, Fort Collins, Colorado, USA.
- Johnson, G. D., and M. S. Boyce. 1990. Feeding trials with insects in the diet of sage grouse chicks. *Journal of Wildlife Management* 54:89-91.
- Johnson, G. D., and M. S. Boyce. 1991. Survival, growth, and reproduction of captive-reared Sage Grouse. *Wildlife Society Bulletin*. 19:88-93.
- Johnson, M. L., and M. S. Gaines. 1990. Evolution of dispersal: theoretical models and empirical test using birds and mammals. *Annual Review of Ecology and Systematics* 21:449-480.
- Kaplan, E.L. and P. Meier. 1958. Nonparametric-estimation from incomplete observations. *Journal of the American Statistical Association* 53: 457-481.
- Kenward, R. E., S. P. Rushton, C. M. Perrins, D. W. Macdonald, and A. B. South. 2002. From marking to modeling: dispersal study techniques for land vertebrates. Pp. 50-71 *in* *Dispersal ecology* (J.M. Bullock, R.E. Kenward, and R.S. Hails, eds.). The British Ecological Society.
- Martin, K., P. B. Stacey, and C. E. Braun. 2000. Recruitment, dispersal, and demographic rescue in spatially-structured white-tailed ptarmigan populations. *Condor* 102:503-516.
- Musil, D. D., J. W. Connelly, and K. P. Reese. 1993. Movements, survival, and reproduction of sage grouse translocated into central Idaho. *Journal of Wildlife Management* 57:85-91.
- Patterson, R. L. 1952. *The sage grouse in Wyoming*. Sage Books, Inc. Denver, Colorado, USA.
- Piertney, S. B., A. D. C. MacColl, P. J. Bacon, P. A. Racey, X. Lambin, and J. F. Dallas. 2000. Matrilineal genetic structure and female-mediated gene flow in red grouse (*Lagopus lagopus scoticus*): an analysis using mitochondrial DNA. *Evolution* 54(1):279-289.

- Pitman, J. C. 2003. Lesser prairie-chicken nest site selection and nest success, juvenile gender determination and growth, and juvenile survival and dispersal in southwestern Kansas. Thesis, Kansas State University, Manhattan, Kansas, USA.
- Pollock, K.H., S.R. Winterstein, C.M. Bunck, and P.D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. *Journal of Wildlife Management* 53: 7-15.
- Quinn, G. P., and M. J. Keogh. 2002. Experimental design and data analysis for biologists. Cambridge University Press.
- Reese, K. P., and J. W. Connelly. 1997. Translocation of sage grouse *Centrocercus urophasianus* in North America. *Wildlife Biology* 3(3/4):235-241.
- Rowland, M. M., and M. J. Wisdom. 2002. Research problem analysis for greater sage-grouse in Oregon. Final Report. Oregon Department of Fish and Wildlife; U.S. Department of the Interior, Bureau of Land Management, Oregon/Washington State Office, and U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage Grouse (*Centrocercus urophasianus*). In A. Poole and F. Gill [eds.], *The birds of North America*, No. 425. The Birds of North America, Inc., Philadelphia, Pennsylvania.
- Segelbacher, G. I. Storch, and J. Tomiuk. 2003. Genetic evidence of capercaillie *Tetrao urogallus* dispersal sources and sinks in the Alps. *Wildlife Biology* 9:267-273.
- U.S. Department of Interior. 1978. A supplement to the northwest Colorado coal regional environmental statement. U.S. Department of Interior, Bureau of Land Management. DES 76-21.
- Thomas, L., and F. Juanes. 1996. The importance of statistical power analysis: an example from *Animal Behaviour*. *Animal Behaviour* 52:856-859.
- U.S. Department of Interior. 1978. A supplement to the northwest Colorado coal regional environmental statement. U.S. Department of Interior, Bureau of Land Management. DES 76-21.
- Wakkinen, W. L., K. P. Reese, and J. W. Connelly. 1992. Sage grouse nest locations in relation to leks. *Journal of Wildlife Management* 56:381-383.
- Western Regional Climate Center. 2003. Monthly Tabular Data. <http://www.wrcc.dri.edu>
- Winterstein, S. R., K. H. Pollock, and C. M. Bunck. 2001. Analysis of survival data from radio telemetry studies. Pages 351-380 in J. J. Millspaugh and J. M. Marzluff, editors. *Radio Tracking and Animal Populations*. Academic Press.

Yoder, J. M. 2004. Ruffed grouse dispersal: relationships with landscape and consequences for survival. Dissertation, Ohio State University, Columbus, Ohio, USA.

Figure 1. Axial Basin/ Danforth Hills, Cold Springs Mountain, and North Moffat greater sage-grouse study sites, Moffat County, Colorado, 2005-2006. (Red indicates primary study areas and black the egg acquisition area).

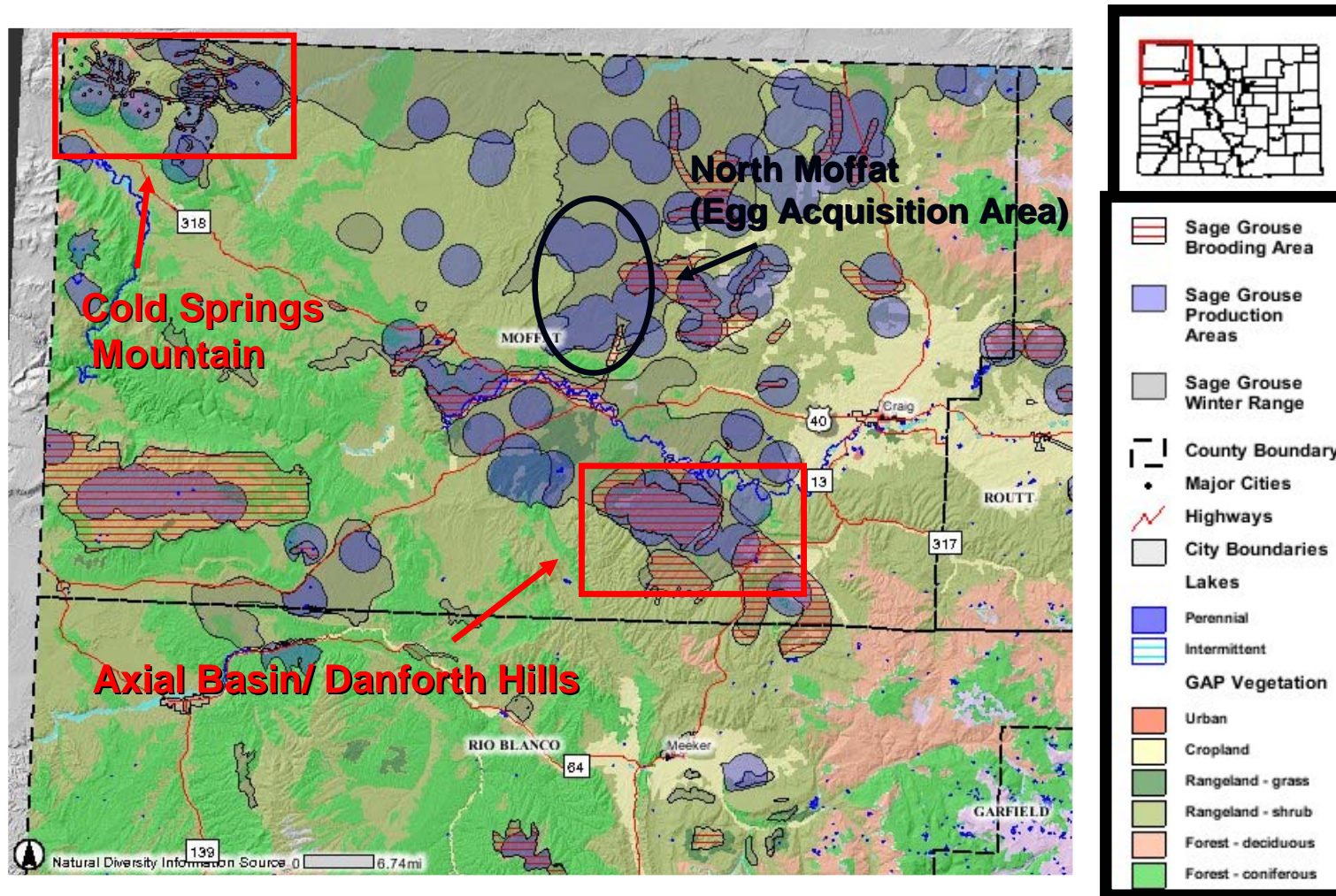


Figure 2. Monthly survival estimates with 95% upper and lower confidence intervals for greater sage-grouse chicks (n = 167) (wild and domestically-hatched) from hatch date (May and June 2005) to first breeding season (March 31 2006) in Moffat County, northwestern Colorado.

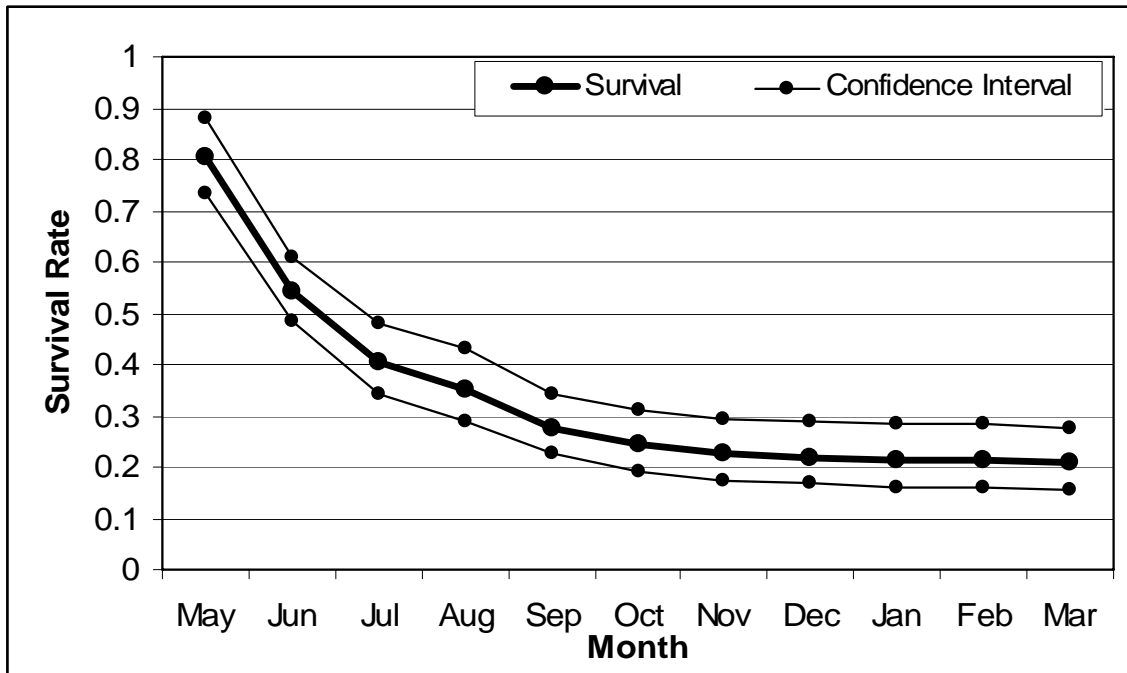


Figure 3. Monthly proportions and fate of hatch-year sage-grouse (i.e., radio-marked as chicks and followed to yearling status) monitored from hatching (May and June 2005) to first breeding season (March 2006) in Moffat County, northwestern Colorado.

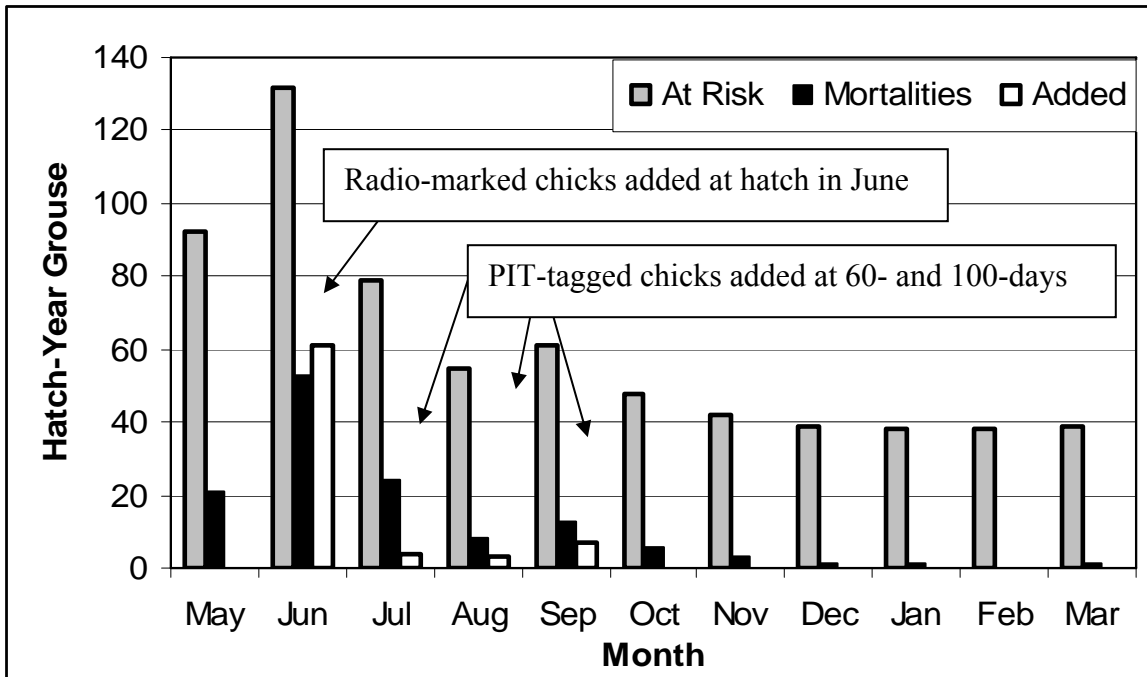


Table 1. Age and location of female greater sage-grouse captured and radio-marked in March and April, 2006 in northwestern Colorado.

Study Area ^a	Total	Adult	Yearling
Axial Basin/ Danforth Hills	27	18	9
East Half	16	10	6
West Half	7	5	2
Danforth Hills	4	3	1
Cold Springs Mountain	18	9	9
Lower Elevation	10	4	6
Higher Elevation	8	5	3
North Moffat	7	3	4
Total	52	30	22

^a Axial Basin/ Danforth Hills Leks: East (CRP, Morgan Gulch 2), West (West Box Elder, Juniper 2), Danforth Hills (SG7 – Burn, SG4 – Little Collom); Cold Springs Mountain : Lower Elevation (Whiskey Draw, G Flats), Upper Elevation (Beaver Basin); North Moffat (Spring Creek, Brushbeat).

Table 2. Age of female greater sage-grouse monitored in northwestern Colorado during the spring and summer, 2006.

Study Area	Total	Adult	Yearling ^a
Axial Basin/ Danforth Hills	75	50	25 (16)
Cold Springs Mountain	59	44	15 (6)
North Moffat	30	26	4
Total	164	120	44 (22)

^a Numbers in parentheses were juveniles radio-marked in the fall of 2006.

Table 3. Yearling greater sage-grouse radio-marked as chicks and juveniles in 2005 and monitored in northwestern Colorado during the spring and summer, 2006.

Study Area	Total	Female	Male
Axial Basin/ Danforth Hills	26	16	10
Cold Springs Mountain	9	6	3
Total	35	22	13

Figure 4. Female greater sage-grouse hatch dates in northwestern Colorado, 2006. (NM = North Moffat, AB = Axial Basin/Danforth Hills, CSM = Cold Springs Mountain).

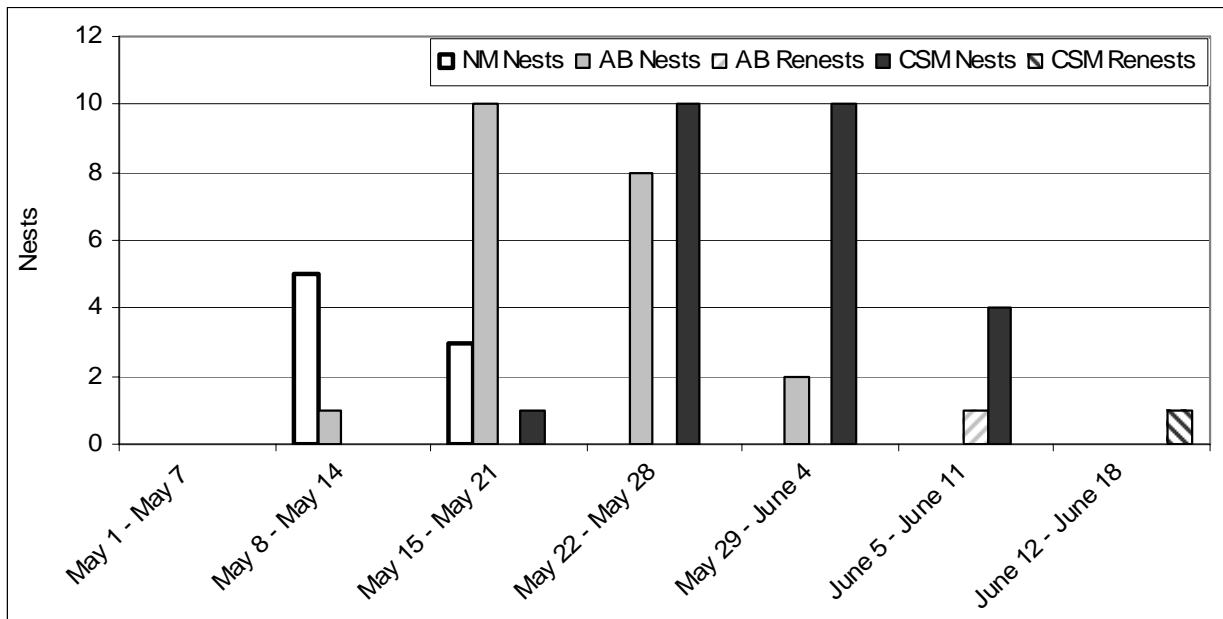


Table 4. Fate of radio-marked female greater sage-grouse monitored during the spring and summer in northwestern Colorado, 2006.

	Axial Basin			Cold Spring Mountain			North Moffat ^a			Northwestern Colorado		
	Total (n = 76)	Adult (n = 50)	Yearling (n = 26)	Total (n = 61)	Adult (n = 44)	Yearling (n = 17)	Total (n = 30)	Adult (n = 26)	Yearling (n = 4)	Total (n = 137)	Adult (n = 94)	Yearling (n = 43)
Female Initiated nesting	55	42	13	58	43	15	25	21	4	113	85	28
Successfully Nested Female	22	18	4	26	21	5	8	8	0	48	39	9
Initial Nest Depredated	30	24	6	27	18	9	9	8	1	57	42	15
Nest Abandoned	4	1	3	1	0	1	4	4	0	5	1	4
Renest Initiated	2	2	0	8	7	1	4	4	0	10	9	1
Renest Successful	1	1	0	1	1	0	0	0	0	2	2	0
Renest Depredated	1	1	0	7	6	1	0	0	0	8	7	1
Renest Fate Unknown	0	0	0	0	0	0	4	4	0	0	0	0
Did Not Nest	8	3	5	0	0	0	0	0	0	8	3	5
Unknown Fate	4	1	3	1	0	1	6	5	1	5	1	4
Mortality (Prelying)	9	4	5	2	1	1	3	3	0	11	5	6

^a Fate of North Moffat study area nests are approximate and not figured into the northwest Colorado total. These nests were not monitored as intensely after eggs were removed and female nesting status confirmed after egg removal (i.e., checking that female did not abandon the nest).

Table 5. Nesting parameters of radio-marked greater sage-grouse monitored during the spring and summer in northwestern Colorado, 2006

	Axial Basin			Cold Springs Mountain			North Moffat ^a			Northwestern Colorado		
	Total (%)	Adult (%)	Yearling (%)	Total (%)	Adult (%)	Yearling (%)	Total (%)	Adult (%)	Yearling (%)	Total (%)	Adult (%)	Yearling (%)
Nest Initiation	87.3 (55/63)	93.3 (42/45)	72.2 (13/18)	100 (58/58)	100 (43/43)	100 (15/15)	100 (25/25)	100 (21/21)	100 (4/4)	93.4 (113/121)	96.6 (85/88)	84.8 (28/33)
Initial Nest Success	38.2 (21/55)	40.5 (17/42)	30.8 (4/13)	43.1 (25/58)	46.5 (20/43)	33.3 (5/15)	32.0 (8/25)	38.1 (8/21)	0.0 (0/4)	40.7 (46/113)	43.5 (37/85)	32.1 (9/28)
Renest Initiation	6.5 (2/31)	8.7 (2/23)	0.0 (0/8)	25.0 (8/32)	31.8 (7/22)	10.0 (1/10)	30.8 (4/13)	40.0 (4/10)	0.0 (0/3)	15.9 (10/63)	20.0 (9/45)	5.6 (1/18)
Renest Success	50.0 (1/2)	50.0 (1/2)	NA	12.5 (1/8)	14.3 (1/7)	0.0 (0/1)	0.0 (0/4)	0.0 (0/4)	NA	20.0 (2/10)	22.2 (2/9)	0.0 (0/1)
Female nest success	40.0 (22/55)	42.9 (18/42)	30.8 (4/13)	44.8 (26/58)	48.8 (21/43)	33.3 (5/15)	32.0 (8/25)	38.1 (8/21)	0.0 (0/4)	42.5 (48/113)	45.9 (39/85)	32.1 (9/28)

^a Fate of North Moffat study area nests are approximate and not figured into the northwest Colorado total. These nests were not monitored as intensely after eggs were removed and female nesting status confirmed after egg removal (i.e., checking that female did not abandon the nest).

Table 6. Spring breeding status and fates of greater sage-grouse captured in Moffat County, Colorado but nesting in Wyoming and Colorado, 2006.

Bird ID	Capture Date	Lek of Capture	Breeding Status	Nesting Fate	Nest/ Mortality Location		State of Nest or Mortality	Clutch Size	R-M ^A	PIT Tagged	Brood Status
					UTM-E	UTM-N					
275	3/26/05	Whiskey Draw	Nested	Successful (5/19)	681620	4541492	Wyoming	6	3	1	Mortality (7/18)
278	3/26/05	Whiskey Draw	Nested	Depredated (5/14)	661683	4537193	Utah				
279	3/26/05	Whiskey Draw	Nested	Successful (5/27)	662487	4543125	Wyoming	6	1	0	Mortality (7/15)
280	3/26/05	Whiskey Draw	Mortality (4/15)	Pre-nesting	672909	4543134	Wyoming				
283	3/26/05	Whiskey Draw	Nested	Successful (5/27)	663051	4538849	Utah	7	3	3	Alive (9/6)
295 ^B	4/20/05	Beaver Basin	Nested	Depredated (5/15)	664001	4539253	Colorado				
			Renested	Successful (6/15)	664194	4539128	Colorado	6	3	2	Alive (9/6)
322 ^C	6/07/05	Marked as chick; Female 290	Nested	Depredated (5/20)	663057	4543153	Wyoming				
399	3/30/06	Beaver Basin	Nested	Successful (6/8)	660637	4537028	Utah	8	3	0	Mortality (7/22)
400	3/30/06	Beaver Basin	Mortality (5/30)	Pre-nesting	666278	4543237	Wyoming				

^A R-M = radio-marked.

^B Female 295's nests were < 800 m (1/2 mile) from 3 Corners. In addition habitats in Wyoming and Utah were used during pre-nesting and brooding.

^C Female 322 was a chick of 290's radio-marked 2 days post-hatch (6/09/05) near Beaver Basin in Moffat County, Colorado.

Table 7. Natal dispersal and breeding season status of female yearling greater sage-grouse (n = 22) radio-marked as chicks in 2005 and monitored through the breeding season 2006 in Moffat County, Colorado.

Area	Yearling ID	Maternal Female	2006 Breeding Status	Distance (km) from:		Nest Fate	Status June 1
				Natal Nest to First Nest	Natal Nest to Avg. Breeding Season Location ^a		
Cold Springs Mountain	C-310-05	C-264-05	Nested	0.20	NA	Successful	Brood
	C-312-05	C-264-05	Nested	0.15	NA	Depredated	Killed on nest (5/10)
	C-313-05	C-302-05	Nested	0.40	NA	Depredated	Broodless
	C-315-05	C-286-05	Nested	1.05	NA	Depredated	Broodless
	C-320-05	C-290-05	Nested	0.81	NA	Successful	Brood
	C-322-05	C-290-05	Nested	10.66	NA	Depredated	Broodless
Axial Basin	A-323-05	A-209-05	Nested	0.91	NA	Depredated	Killed on nest (5/18)
	A-327-05	A-230-05	Did Not Nest	NA	8.04	NA	Alive
	A-329-05	A-230-05	Nested	0.91	NA	Abandoned	Broodless
	* A-331-05	A-158-05	Pre-nesting	NA	1.66	NA	Mortality (4/26)
	A-335-05	A-173-05	Nested	1.75	NA	Depredated	Broodless
	A-339-05	A-173-05	Pre-nesting	NA	8.49	NA	Mortality (4/19)
	A-341-05	A-173-05	Pre-nesting	NA	2.08	NA	Mortality (4/12)
	A-345-05	A-209-05	Did Not Nest	NA	1.05	NA	Alive
	A-346-05	A-164-05	Nested	0.43	NA	Depredated	Alive
	A-348-05	A-155-05	Nested	0.31	NA	Depredated	Alive
	A-349-05	A-176-05	Nested	1.12	NA	Successful	Brood
	A-351-05	A-196-05	Nested	11.69	NA	Depredated	Alive
	A-353-05	A-238-05	Nested	1.87	NA	Depredated	Alive
	A-355-05	A-196-05	Nested	0.35	NA	Successful	Brood
	A-357-05	A-191-05	Did Not Nest	NA	2.74	NA	Alive
A-358-05	A-191-05	Nested	0.41	NA	Successful	Brood	

^a Mean distance between natal nest and all locations from March 1 to June 1 (or mortality). * Domestically-hatched chick; natal nest for domestically-hatched chicks refers to the location where chicks were introduced into (adopted by) wild broods.

Table 8. Natal dispersal and breeding season status of male yearling greater sage-grouse (n = 13) radio-marked as chicks in 2005 and monitored through the breeding season 2006 in Moffat County, Colorado.

Area	Yearling ID	Maternal Female	Distance (km) from Natal Nest-Avg. Breeding Season Location	Status June 1
Cold Springs Mountain	C-314-05	C-286-05	4.39	Alive
	C-317-05	C-265-05	3.89	Alive
	C-321-05	C-290-05	18.92	Mortality (4/29)
Axial Basin	A-324-05	A-213-05	7.08	Alive
	A-325-05	A-213-05	26.04	Alive
	A-328-05	A-230-05	7.54	Mortality (4/14)
	A-332-05	A-158-05	2.09	Mortality (5/15)
	* A-336-05	A-173-05	10.58	Mortality on lek (5/27)
	A-337-05	A-173-05	9.42	Mortality on lek (3/16)
	A-340-05	A-173-05	3.72	Mortality (5/16)
	A-343-05	A-209-05	2.63	Mortality (5/21)
	A-347-05	A-155-05	1.67	Alive
A-352-05	A-238-05	1.74	Alive	

^a Mean distance between natal nest and all locations from March 1 to June 1 (or mortality).

* Domestically-hatched chick; natal nest for domestically-hatched chicks refers to the location where chicks were introduced into (adopted by) wild broods.

Table 9. Natal dispersal (km) of greater sage-grouse chicks radio-marked in the spring of 2005 and monitored through the breeding season 2006 in Moffat County, Colorado.

From Natal Nest: ^A	Axial Basin/ Danforth Hills (<i>n</i> = 26)	Cold Springs Mountain (<i>n</i> = 9)	Northwest Colorado (<i>n</i> = 35)
To First Nest:	Mean (SE)	Mean (SE)	Mean (SE)
Females	2.0 (\pm 1.1) (<i>n</i> = 10)	2.2 (\pm 1.7) (<i>n</i> = 6)	2.1 (\pm 0.9) (<i>n</i> = 16)
To Average Breeding Season Location:	Mean (SE)	Mean (SE)	Mean (SE)
Females	4.0 (\pm 1.4) (<i>n</i> = 6)		4.0 (\pm 1.4) (<i>n</i> = 6)
Males	7.3 (\pm 2.3) (<i>n</i> = 10)	9.1 (\pm 4.9) (<i>n</i> = 3)	7.7 (\pm 2.0) (<i>n</i> = 13)
Combined:	Mean (SE)	Mean (SE)	Mean (SE)
Females	2.7 (\pm 0.9) (<i>n</i> = 16)	2.2 (\pm 1.7) (<i>n</i> = 6)	2.6 (\pm 0.8) (<i>n</i> = 22)

^A Natal dispersal is the straight-line distance between the natal nest and the first nesting attempt for females that nested or the average breeding Season locations (15 March 15 – 15 May, 2006) for females that did not nest and males.

Figure 5. The straight-line distance (km) between the natal nest and first breeding season nest of known yearling female greater sage-grouse radio-marked as chicks in 2005 and followed through the breeding season in Moffat County, Colorado during 2006.

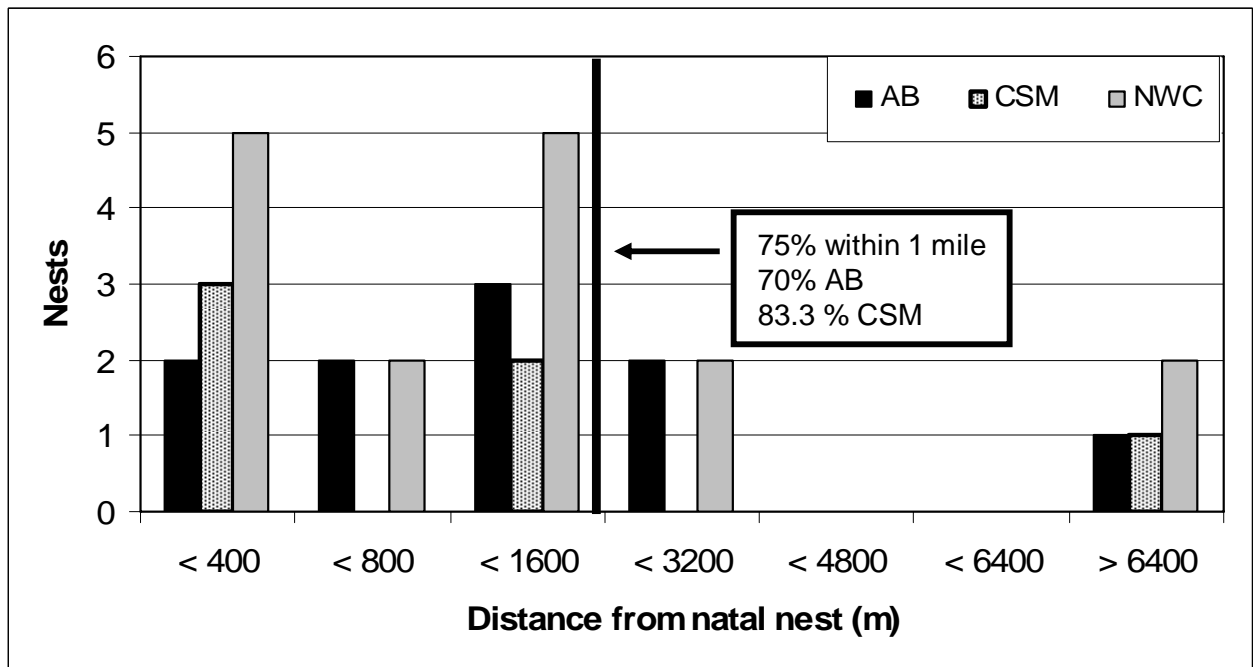


Figure 6. Frequency distribution of natal dispersal for known yearling male and female greater sage-grouse radio-marked as chicks in 2005 and followed through the breeding season in Moffat County, Colorado during 2006.

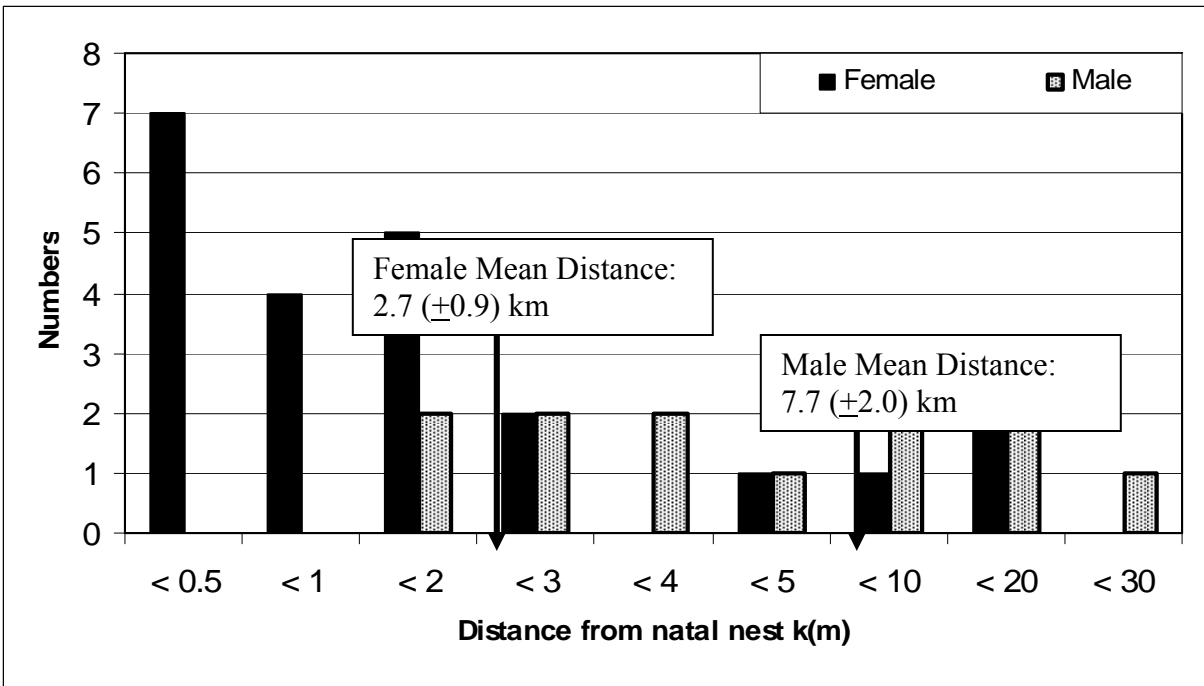


Table 10. Timing of death and breeding status mortalities of female greater sage-grouse from 1 March to 31 November 2006 in Moffat County, Colorado.

	Axial Basin/ Danforth Hills (<i>n</i> = 76)	Cold Springs Mountain (<i>n</i> = 61)	Total (<i>n</i> = 137)
Total	28	20	48
Month of Death:			
March	3	3	6
April	4	0	4
May	5	2	7
June	1	2	3
July	3	2	5
August	7	3	10
September	3	5	8
October	2	3	5
November	0	0	0
Breeding Status Mortalities:			
Pre-Nesting	9	2	11
Nesting	3	2	5
Renesting	0	0	0
Early Brood (May – June)	0	3	3
Late Brood (Jul – Aug)	3	2	5
Broodless (May – Aug)	8	3	11
Fall (Sep – Oct)	5	8	13
Age at Death:			
Adult	19	15	34
Yearling	9	5	14

Table 11. Date, location, and altitude of greater sage-grouse mortalities due to West Nile virus (WNV) in northwestern Colorado, 2006.

Bird ID	Study Area ^A	Capture Date	Date Last Alive	Date Found Dead	Age at Death ^B	Location	UTM-E	UTM-N	Altitude (m)	Comments
199	AB	4/14/05	7/30/06	8/02/06	A	Moffat County, Colorado	254979	4462751	2189	Initiated nest 4/18, but depredated on 5/9
214	AB	3/17/05	8/11/06	8/19/06	A	Moffat County, Colorado	255152	4464026	2135	Initiated nest 4/24, but depredated on 5/1
294	CSM	4/20/05	6/07/06	6/08/06	A	Moffat County, Colorado	676255	4531063	2619	w/ brood at age 10 days; chicks w/ random female 6/09, but 2 dead and 1 missing on 6/12
389	AB	3/31/06	8/24/06	8/31/06	A	Moffat County, Colorado	254135	4463311	2163	Hatched on 6/5; one chick still alive (1/01/07), all other chicks died before 8/24
400	CSM	3/30/06	5/26/06	5/30/06	Y	Sweetwater County, Wyoming	666278	4543237	2764	Did not attempt to nest; found on the SE side of Pine Mtn., Wyoming; in poor body condition
733	AB	7/01/06	7/29/06	8/04/06	chick	Moffat County, Colorado	258909	4471750	1895	Random chick caught with 289's brood on 7/1; chick approximately 76 days old at death

^A AB = Axial Basin/ Danforth Hills and CSM = Cold Springs Mountain

^B A = adult and Y = yearling

Table 12. Summary of greater sage-grouse eggs collected in northwestern Colorado 2004 – 2006.

Year	Total Eggs ^a	EA Eggs ^b	Laying Eggs ^c	Incub. Eggs ^d	Ab. Eggs ^e	Average Refrigeration Time (days)	Total Hatched (%)	EA Hatched (%)	Stored Eggs Hatched (%)	Total Died in Egg ^f	Total Sterile/ No Dev. ^g
2004	39	36	22	14	3	< 7 (range 2-7)	79.5 (31/39)	80.6 (29/36)	NA	NA	NA
2005	82	62	36	24	22	7.9 (range 3-12)	58.5 (48/82)	70.0 (42/60)	47.3 (18/38)	14	4
2006	102	76	48	28	26	7.8 (range 5-11)	53.9 (55/102)	64.5 (49/76)	43.9 (29/66)	15	12

^aIncludes all eggs collected from both abandoned/depredated nests and egg acquisition nests.

^bEggs collected from females designated for egg acquisition (EA).

^cEggs collected from laying EA females (prior to incubation).

^dEggs collected from incubating females.

^eEggs collected from abandoned/ depredated nests.

^fEggs collected from EA females where embryos died in the egg (i.e., showed signs of development)..

^gEggs collected from EA females that were either sterile or showed no signs of development.

Table 13. Summary of female status and hatching rates for greater sage-grouse eggs depending on collection method (Laying, Incubating, etc.) in northwestern Colorado 2005 – 2006.

	Laying Eggs (%)	Incubating Eggs (%)	Incubating: Abandoned/ depredated Eggs (%)	Unknown: Laying/ Incubating (%)
2005 (n=82) ^a	50.0 (18/36) ^b	100 (24/24)	30.0 (6/20)	0 (0/2)
2006 (n=102)	56.3 (27/48)	78.6 (22/28)	23.1 (6/26)	NA
Total (n=184)	53.6 (45/84)	88.5 (46/52)	23.9 (11/46)	0 (0/2)

^a The *n* for each year and combined total represents all the eggs collected for that period and is equal to the sum of the totals for each category.

^b The percentages represents the proportions hatching within that category.

Table 14. Percentage of domestically-hatched chicks surviving to brood adoption depending on how the eggs were originally collected and on whether they were stored in a refrigerator (5 – 11 days) before placement in the incubator, Northwestern Colorado 2005 – 2006.

Year	Stored (%)	Laying (%)	Incubating (%)	Incubating: Abandoned/ depredated (%)
2005 (n=32) ^a	44.4 (8/18)	44.4 (8/18)	83.3 (20/24)	66.7 (4/6)
2006 (n=37)	58.6 (17/29)	70.4 (19/27)	77.3 (17/22)	16.7 (1/6)
Total (n=69)	53.2 (25/47)	60.0 (27/45)	80.4 (37/46)	41.7 (5/12)

^a The *n* for each year and combined total represents the number of successfully hatched chicks introduced into wild broods.

^b The percentages represents the proportion of successful chicks within each category that were introduced into wild broods.

Table 15. Summary of fates of domestically-raised greater sage-grouse chicks in northwestern Colorado in 2004 - 2006.

Year	Total Hatched Chicks	Chick Fate			Cause of Death		
		Successful Chicks (%)	Total Dead Chicks (%)	Deformities ^a (%)	Euthanized. (%)	Human Error (%)	Unknown Cause ^b (%)
2004	30	60.0 (18/30)	40.0 (12/30)	16.7 (5/30)	58.3 (7/12)	33.3 (4/12)	8.3 (1/12)
2005	48	66.7 (32/48)	33.3 (16/48)	29.2 (14/48)	31.3 (5/16)	6.3 (1/16)	62.3 (10/16)
2006	55	67.3 (37/55)	34.5 (19/55)	14.8 (8/54)	15.8 (3/19)	10.5 (2/19)	73.7 (14/19)

^a Deformities included splayed legs, seizures, malformed appendages, or other irregularities. This did not determine that a chick would be euthanized if it could recover after hatching (i.e., in 2005 and 2006 partially splayed legs or curled toes on chicks did straighten out after the chicks were removed from the hatcher).

^b Involves cases when chicks are found dead in the outside or inside of brooders and pens and cause of death is unable to be determined upon inspection in the field. Probable causes could include any one or a combination of the following: malnutrition, internal abnormalities (seizures, gastrointestinal problems, birth defects, etc.), or environmental factors and stresses (overheating, feeding schedules, substrate, etc.).

Table 16. Initial weights (post-hatching), final weights, and average daily weight gains (grams/ day) for domestically-hatched chicks raised for either ≤ 4 days (Treatment 1) or ≥ 4 days (Treatment 2) during 2005 and 2006 in Moffat County, Colorado. Chicks were either successful (introduced into wild broods) or failed (mortality in captivity before introduction attempt). Bold indicates significant difference between successful and failed chicks within each treatment.

	2005	2006	Combined
Initial Weight	30.1 (± 0.4) (n = 47)	28.8 (± 0.4) (n = 55)	29.4 (± 0.6) (n = 102)
Treatment:			
(1) ≤ 4 days (Mean 2.9 days; range: 1 – 4 days)			
Success			
Initial Weight (g)	31.3 (± 0.5) (n = 16)	29.3 (± 0.8) (n = 27)	30.1 (± 0.4) (n = 43)
Final Weight (g)	31.5 (± 0.8) (n = 16)	35.02 (± 0.7) (n = 27)	33.6 (± 0.6) (n = 43)
Weight Gain (g/day)	0.2 (± 0.3) (n = 16)	1.7 (± 0.2) (n = 27)	0.9 (± 0.2) (n = 43)
Failure			
Initial Weight (g)	29.8 (± 0.8) (n = 12)	28.6 (± 0.8) (n = 12)	29.2 (± 0.6) (n = 24)
Final Weight (g)	29.2 (± 2.0) (n = 8)	31.6 (± 0.8) (n = 12)	30.1 (± 1.2) (n = 17)
Weight Gain (g/day)	-0.1 (± 0.5) (n = 8)	0.8 (± 0.3) (n = 12)	0.4 (± 0.3) (n = 17)
(2) ≥ 4 days (Mean 6.5 days; range: 5 – 9 days)			
Success			
Initial Weight (g)	29.1 (± 0.6) (n = 16)	29.6 (± 0.6) (n = 10)	29.3 (± 0.4) (n = 26)
Final Weight (g)	47.4 (± 2.3) (n = 16)	40.8 (± 0.6) (n = 10)	44.9 (± 2.0) (n = 26)
Weight Gain (g/day)	2.4 (± 0.4) (n = 16)	1.9 (± 0.2) (n = 10)	2.2 (± 0.2) (n = 26)
Failure			
Initial Weight (g)	30.2 (± 1.4) (n = 3)	26.5 (± 0.1) (n = 8)	27.5 (± 0.9) (n = 11)
Final Weight (g)	33.1 (± 3.7) (n = 3)	33.1 (± 1.4) (n = 8)	33.1 (± 1.3) (n = 11)
Weight Gain (g/day)	0.4 (± 0.8) (n = 3)	1.1 (± 0.2) (n = 8)	0.9 (± 0.3) (n = 11)

Table 17. Broods and chicks of radio-marked females monitored during the spring and summer in northwestern Colorado, 2006.

	Axial Basin/ Danforth Hills	Cold Springs Mountain	Total
Total Broods	22	26	48
Radio-marked Broods	21	26	47
Brood Success at 14 days	81.0% (17/21)	88.5% (23/26)	85.1% (40/47)
Brood Success at 28 days	71.4% (15/21)	76.9% (20/26)	74.5% (35/47)
Brood Success at 16 weeks	47.6% (10/21)	46.2% (12/26)	46.8% (22/47)
Total Chicks Radio-marked	100	94	194
Wild Chicks Radio-marked	69	75	144
Domestic Chicks Radio-marked	21	14	35
Total Chicks PIT Tagged	68	85	153
PIT tagged chicks Radio-marked	10	5	15
Censored Radio-marked Chicks:	30	25	55
Dropped Transmitter	2	1	3
Human Error	2	0	2
Radio-failure	9	7	16
Missing/ Unaccounted for	17	17	34
Wild Chick Survival to 14 days	80.8% (<i>n</i> = 43)	75.5% (<i>n</i> = 44)	78.3% (<i>n</i> = 87)
Domestic Chick Survival to 14 days	52.6% (<i>n</i> = 10)	35.7% (<i>n</i> = 1)	43.3% (<i>n</i> = 11)
Wild Chick Survival to 28 days	77.0% (<i>n</i> = 28)	68.6 (<i>n</i> = 36)	72.8% (<i>n</i> = 64)
Domestic Chick Survival to 28 days	47.6% (<i>n</i> = 9)	6.7% (<i>n</i> = 1)	39.4% (<i>n</i> = 10)
Wild Chick Survival to 16 weeks	38.5% (<i>n</i> = 11)	41.3% (<i>n</i> = 19)	38.5% (<i>n</i> = 30)
Domestic Chick Survival to 16 weeks	36.1% (<i>n</i> = 6)	0	30.4% (<i>n</i> = 6)

Figure 7. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) of radio-marked greater sage-grouse broods ($n = 47$) and chicks (both wild- and domestically-hatched; $n = 175$) and from hatch to 16 weeks of age in Moffat County, northwest Colorado (NWC) 2006.

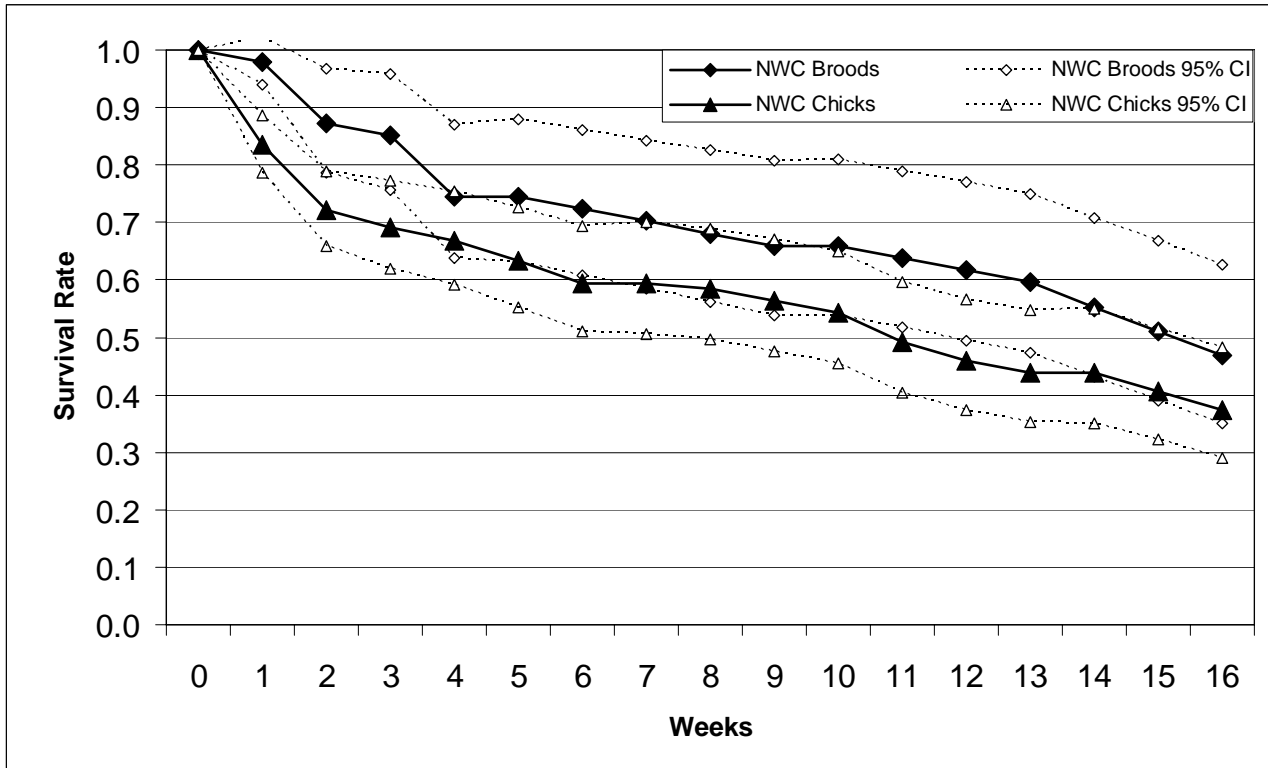


Figure 8. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) of radio-marked greater sage-grouse chicks (wild-hatched) from hatch to 16 weeks of age in the Axial Basin (AB) ($n = 69$) and Cold Springs Mountain (CSM) ($n = 75$) study areas in Moffat County, Colorado 2006 (Log-rank $\chi^2_1 = 0.01$, $P = 0.9343$).

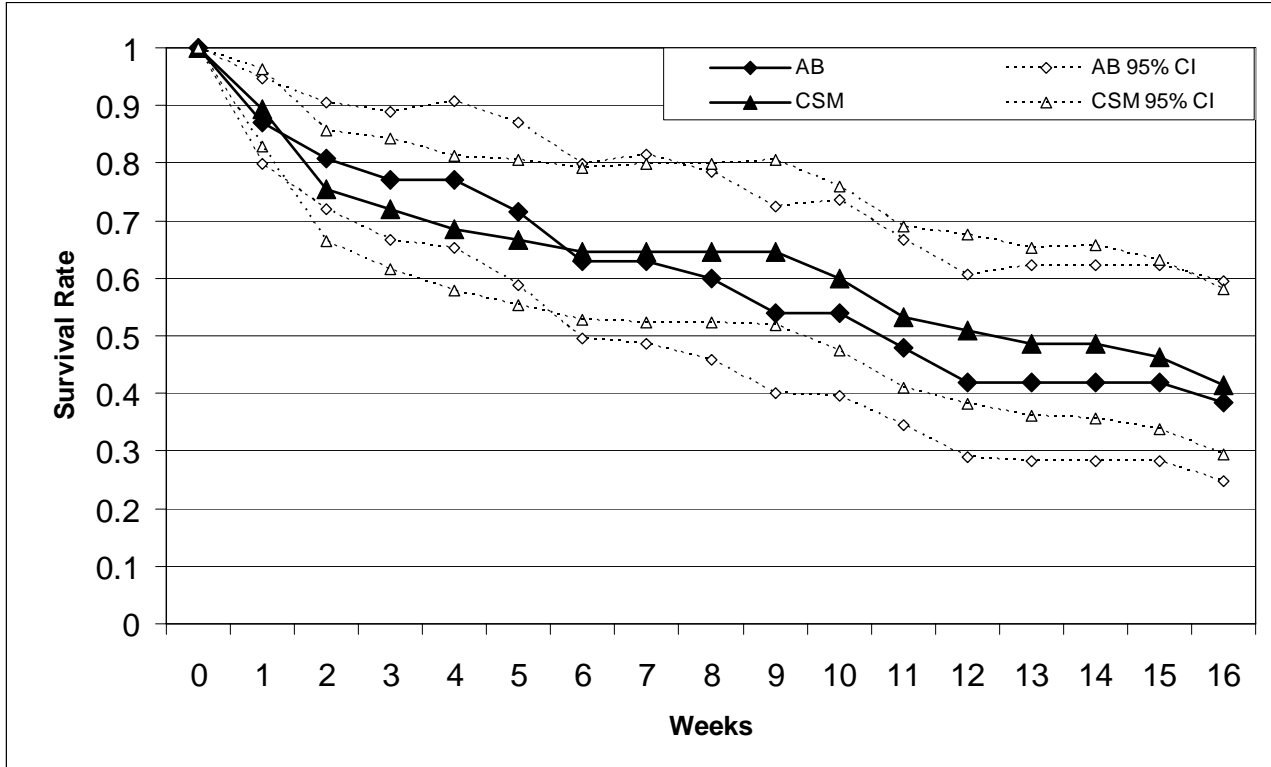


Figure 9. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) of wild-hatched (W-H) ($n = 145$) and domestically-hatched (D-H) ($n = 30$) radio-marked greater sage-grouse chicks from hatch (or adoption date for D-H chicks) to 16 weeks of age in Moffat County, Colorado 2006 (Log-rank $\chi^2_1 = 5.78$, $P = 0.0162$).

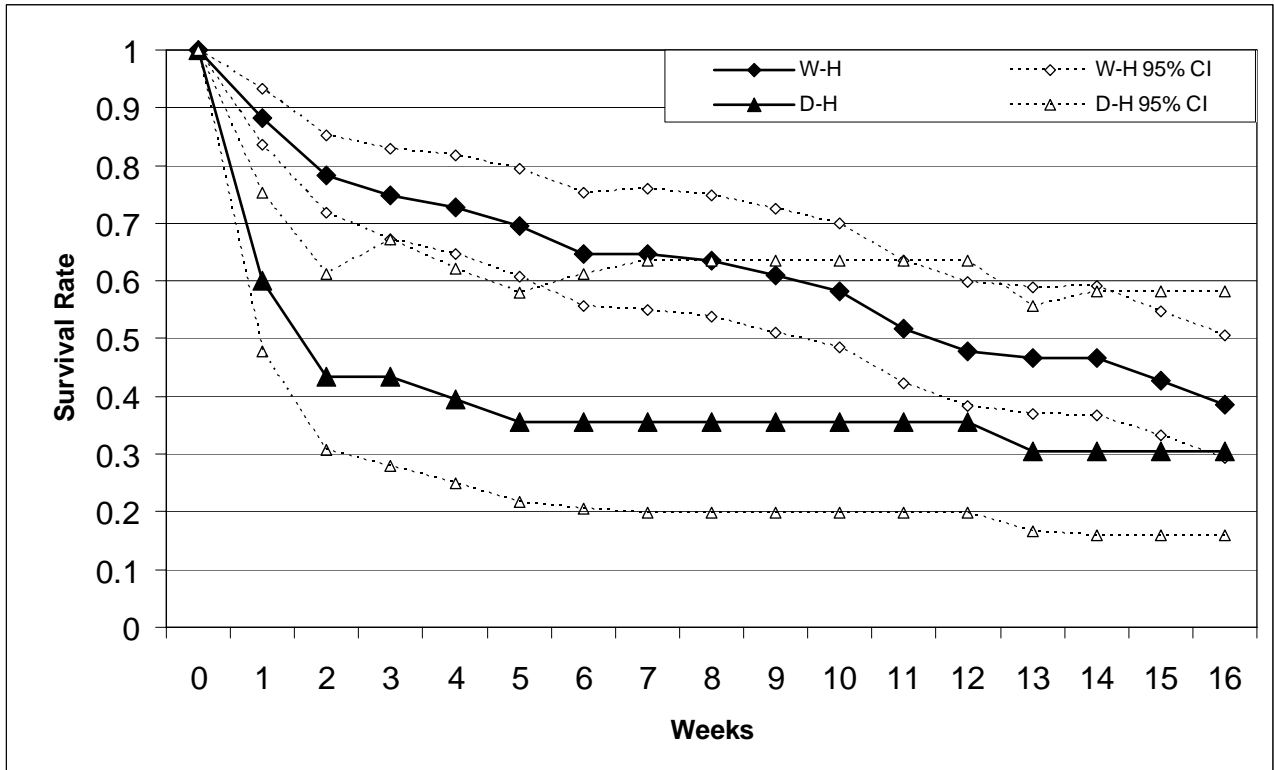


Figure 10. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) of domestically-hatched (D-H) radio-marked greater sage-grouse chicks from age at adoption into wild broods to 16 weeks of age in the Axial Basin (AB) ($n = 19$) and Cold Springs Mountain (CSM) ($n = 11$) study areas in Moffat County, Colorado 2006.

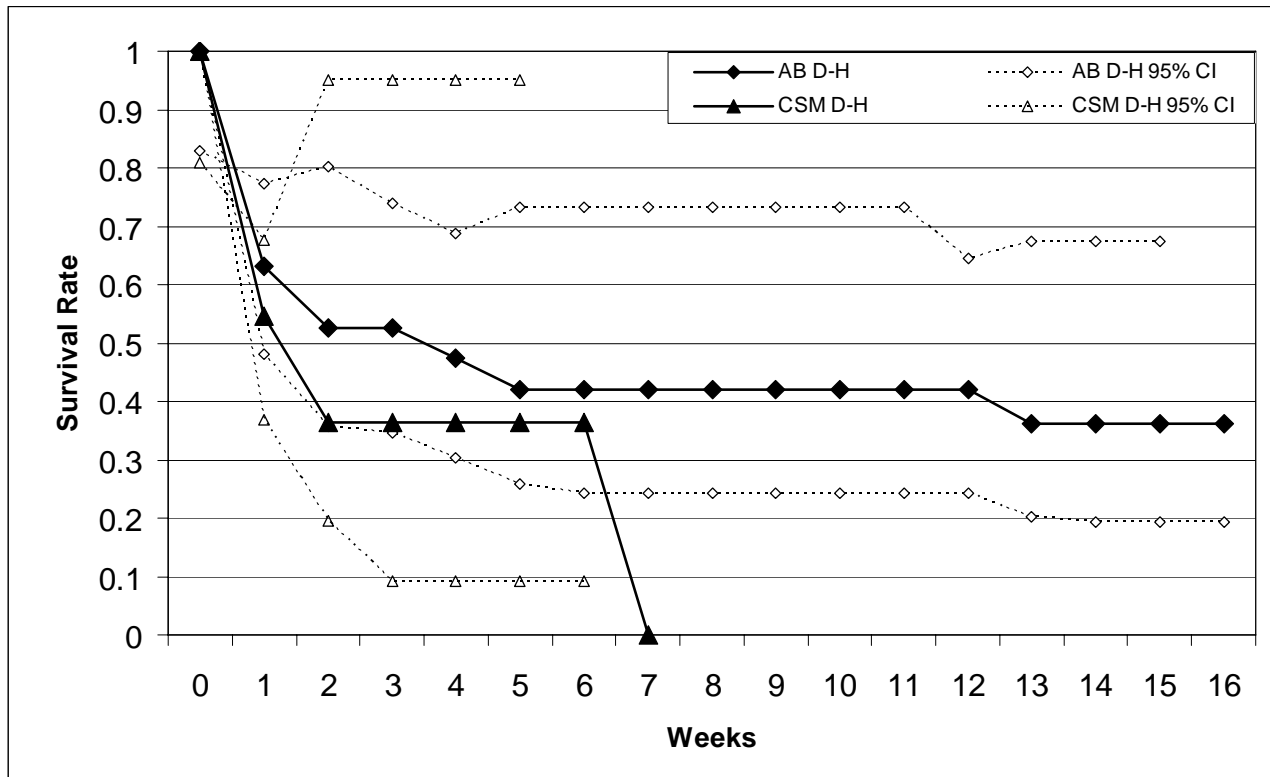


Figure 11. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) of Axial Basin wild-hatched (W-H) ($n = 69$) and domestically-hatched (D-H) ($n = 19$) radio-marked greater sage-grouse chicks from hatch (or adoption date for D-H chicks) to 16 weeks of age in Moffat County, Colorado 2006 (Log-rank $\chi^2_1 = 1.18$, $P = 0.2765$).

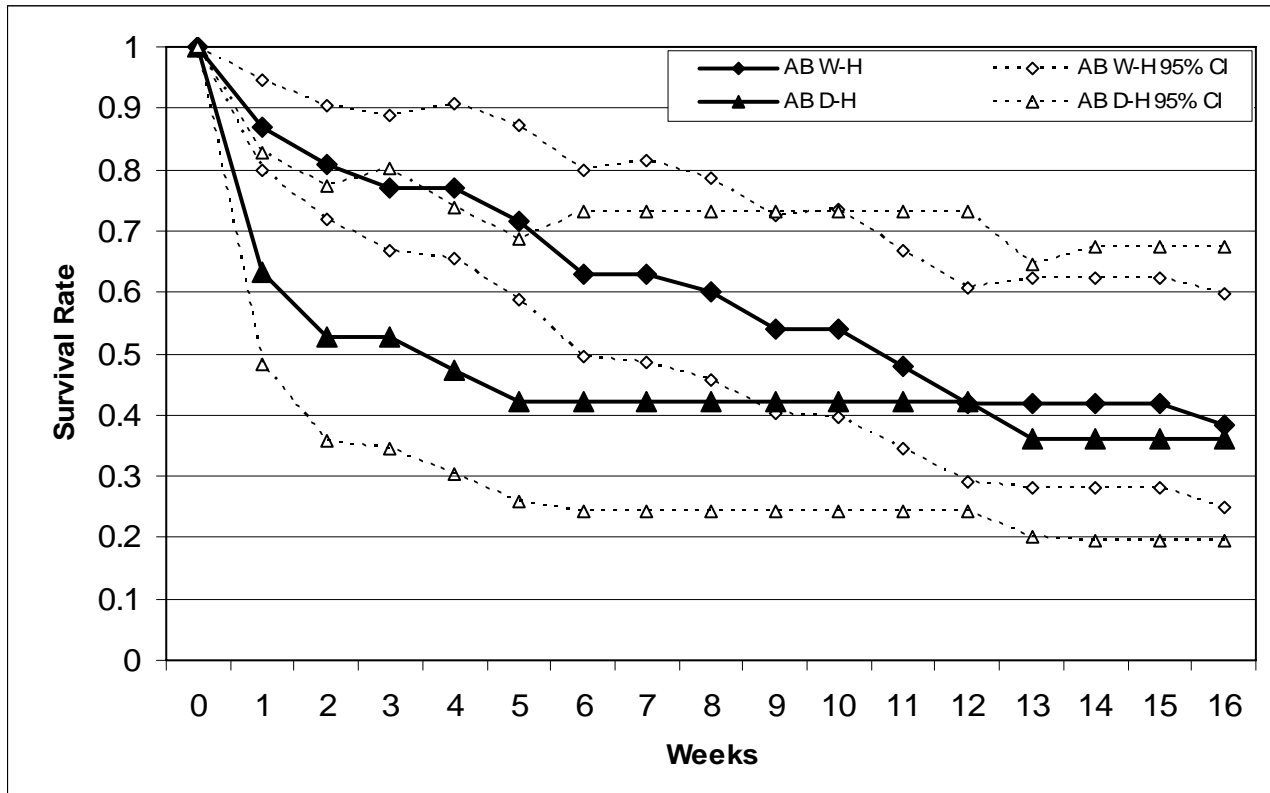


Figure 12. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for domestically-hatched (D-H) radio-marked greater sage-grouse chicks raised from 1 to 4 days of age (Treatment 1: TRT1) ($n = 23$) and 5 to 9 days of age (Treatment 2: TRT2) ($n = 7$) in Moffat County, Colorado 2006. Survival rate is estimated from the adoption age of the D-H chick to 16 weeks post introduction into wild broods.

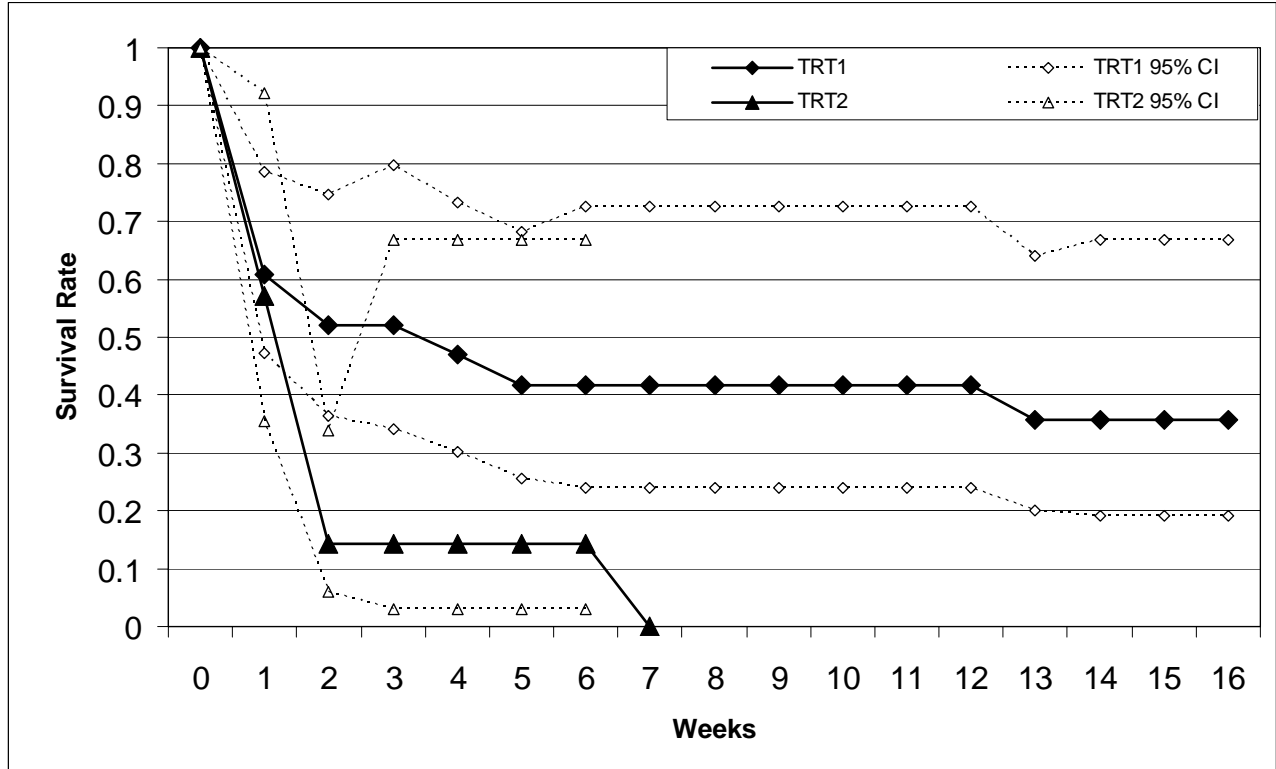


Figure 13. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for greater sage-grouse broods radio-marked in 2005 ($n = 32$) and 2006 ($n = 47$) and monitored from hatch to 16 weeks of age in Moffat County, Colorado (Log-rank $\chi^2_1 = 0.01$, $P = 0.9222$).

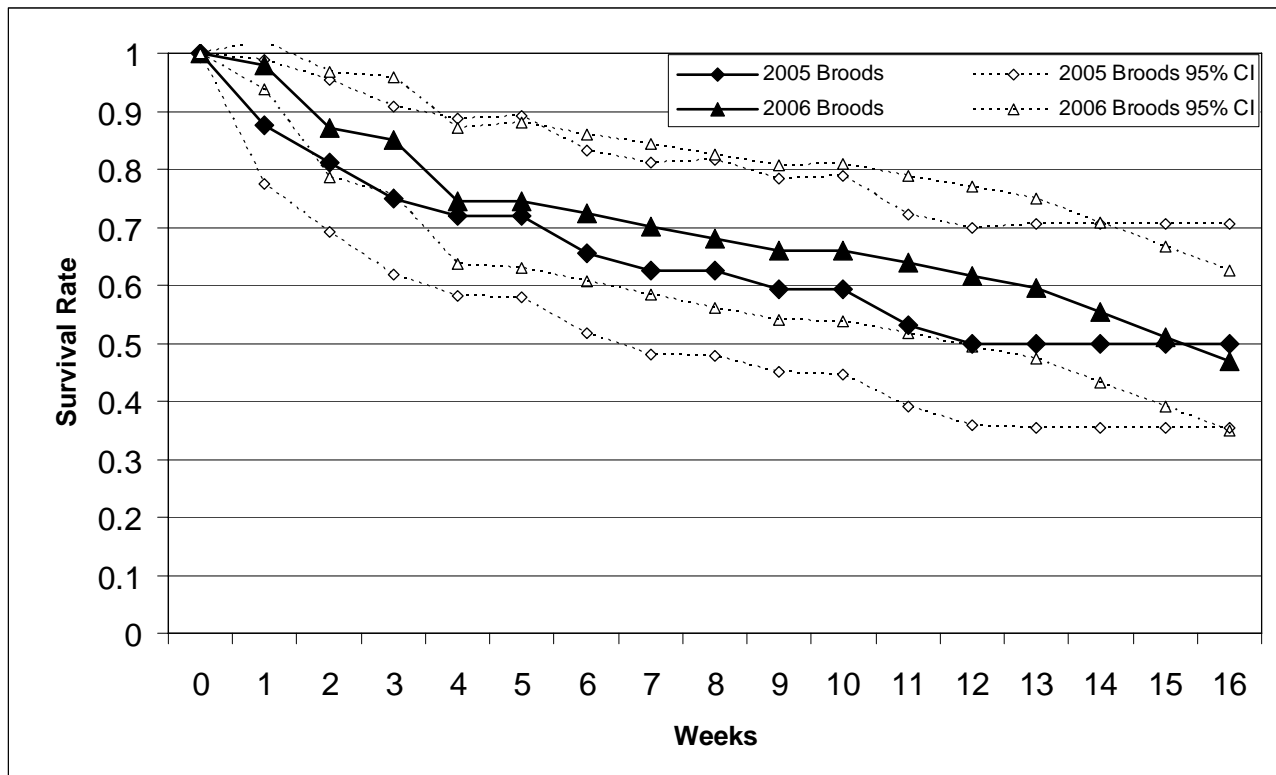


Figure 14. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for greater sage-grouse chicks (both wild-hatched and domestically-hatched) radio-marked in 2005 ($n = 147$) and 2006 ($n = 175$) and monitored from hatch (or adoption age for domestically-hatched) to 16 weeks of age in Moffat County, Colorado (Log-rank $\chi^2_1 = 1.27$, $P = 0.5125$).

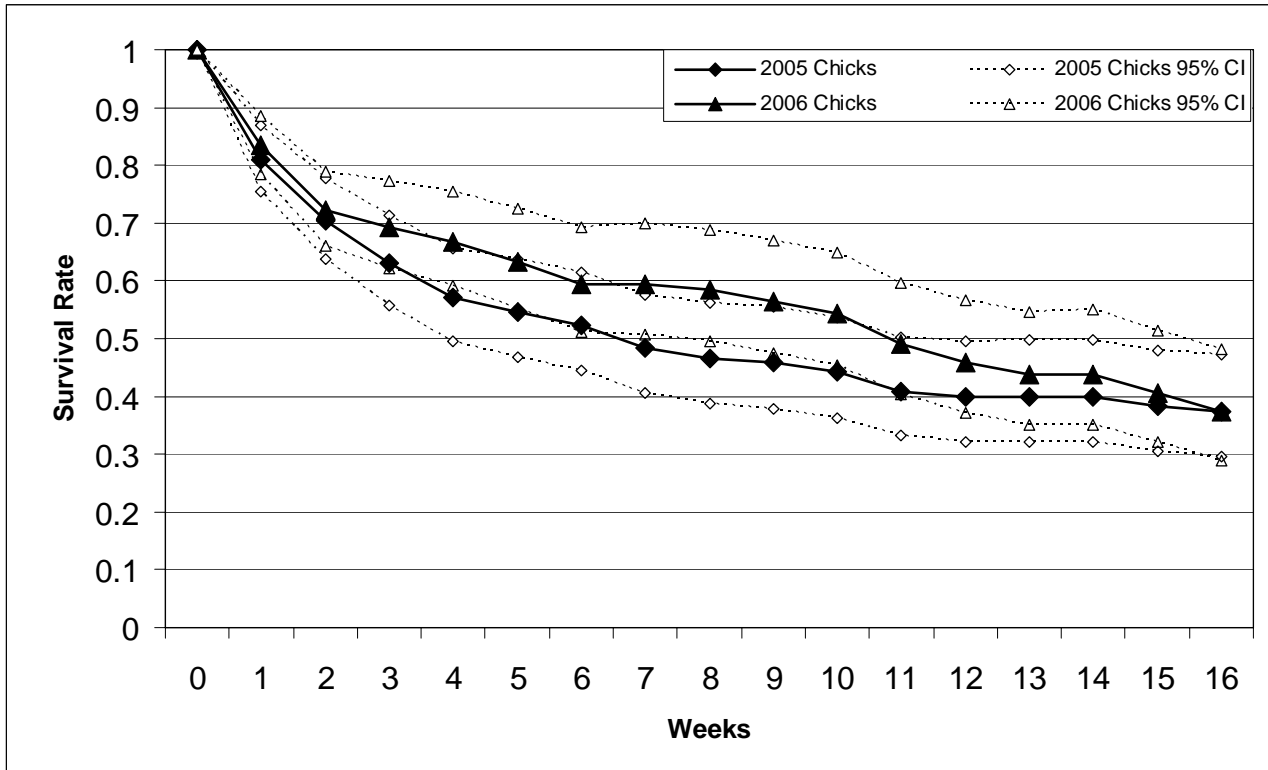


Figure 15. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for wild-hatched (W-H) greater sage-grouse chicks radio-marked in 2005 ($n = 121$) and 2006 ($n = 145$) and monitored from hatch to 16 weeks of age in Moffat County, Colorado (Log-rank $\chi^2_1 = 1.07$, $P = 0.3003$).

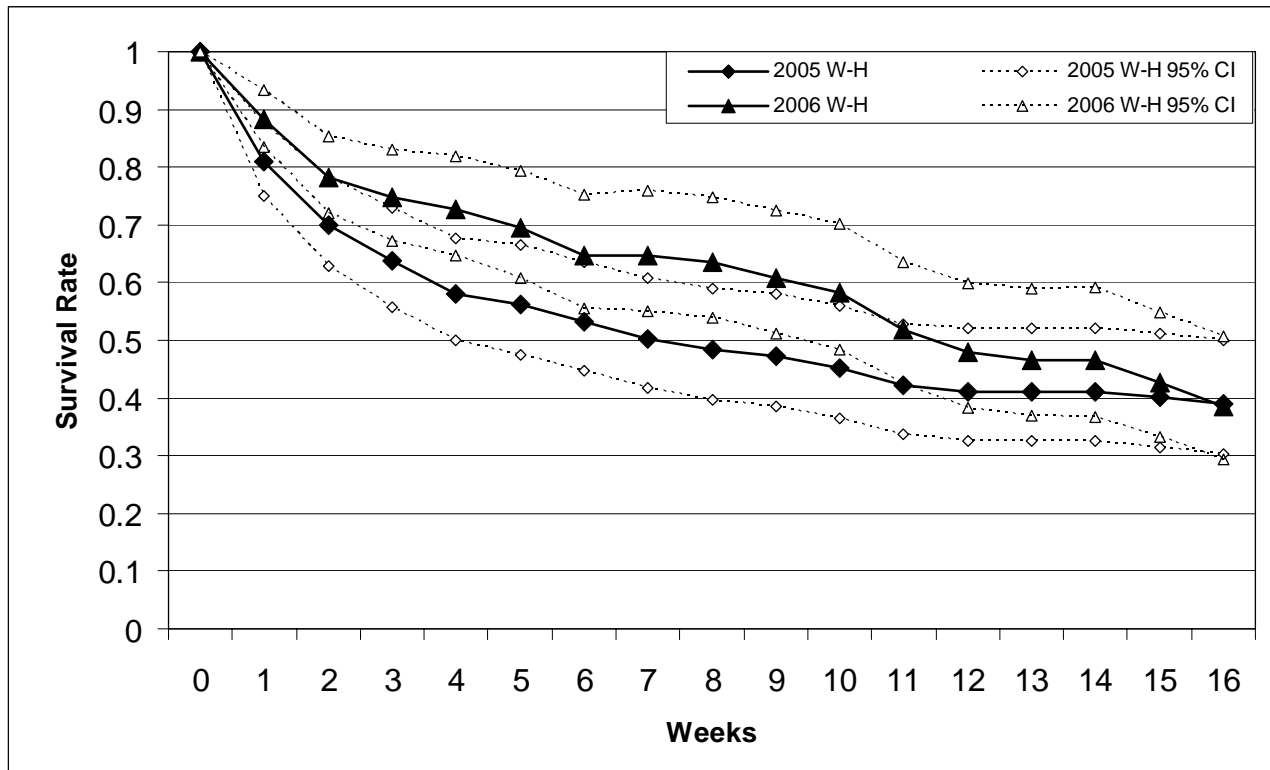


Figure 16. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for wild-hatched greater sage-grouse chicks radio-marked in 2005 ($n = 65$) and 2006 ($n = 69$) and monitored from hatch to 16 weeks of age in the Axial Basin (AB) study area, Moffat County, Colorado (Log-rank $\chi^2_1 = 0.11$, $P = 0.7410$).

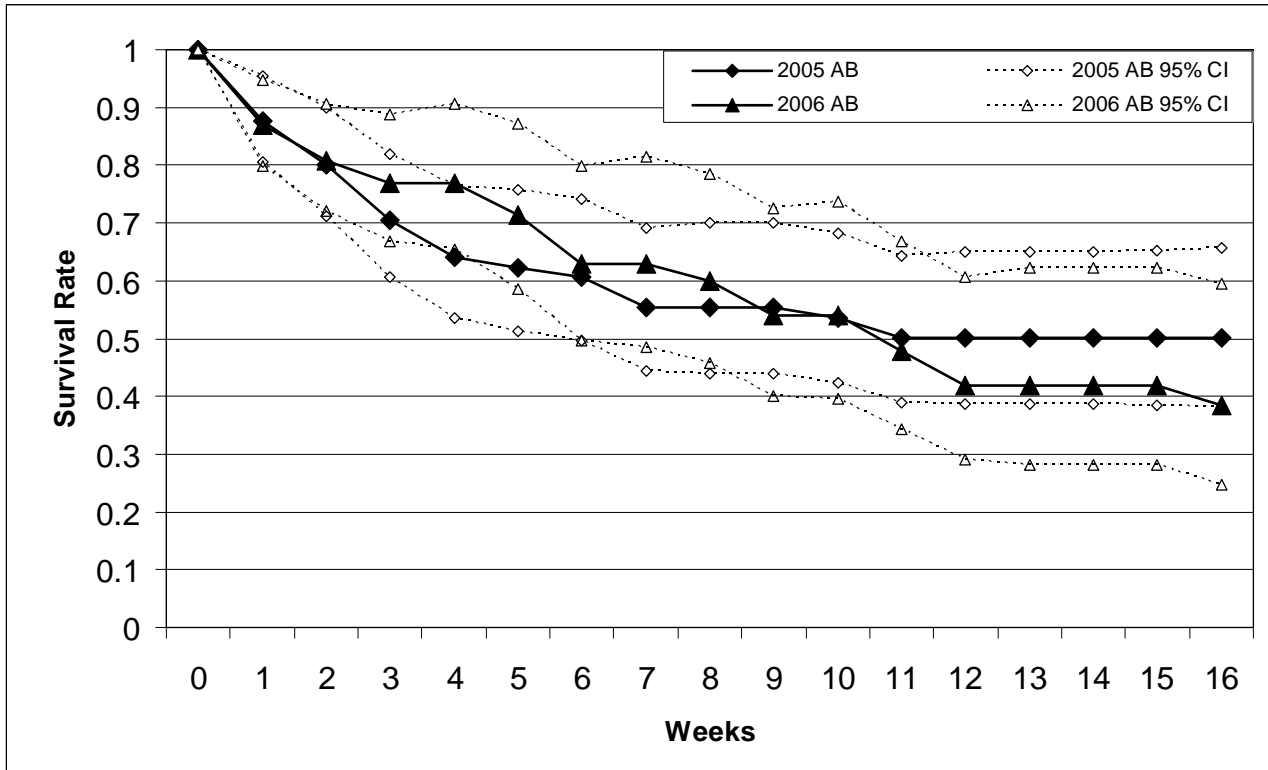


Figure 17. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for wild-hatched greater sage-grouse chicks radio-marked in 2005 ($n = 56$) and 2006 ($n = 75$) and monitored from hatch to 16 weeks of age in the Cold Springs Mountain (CSM) study area, Moffat County, Colorado (Log-rank $\chi^2_1 = 5.13$, $P = 0.0235$).

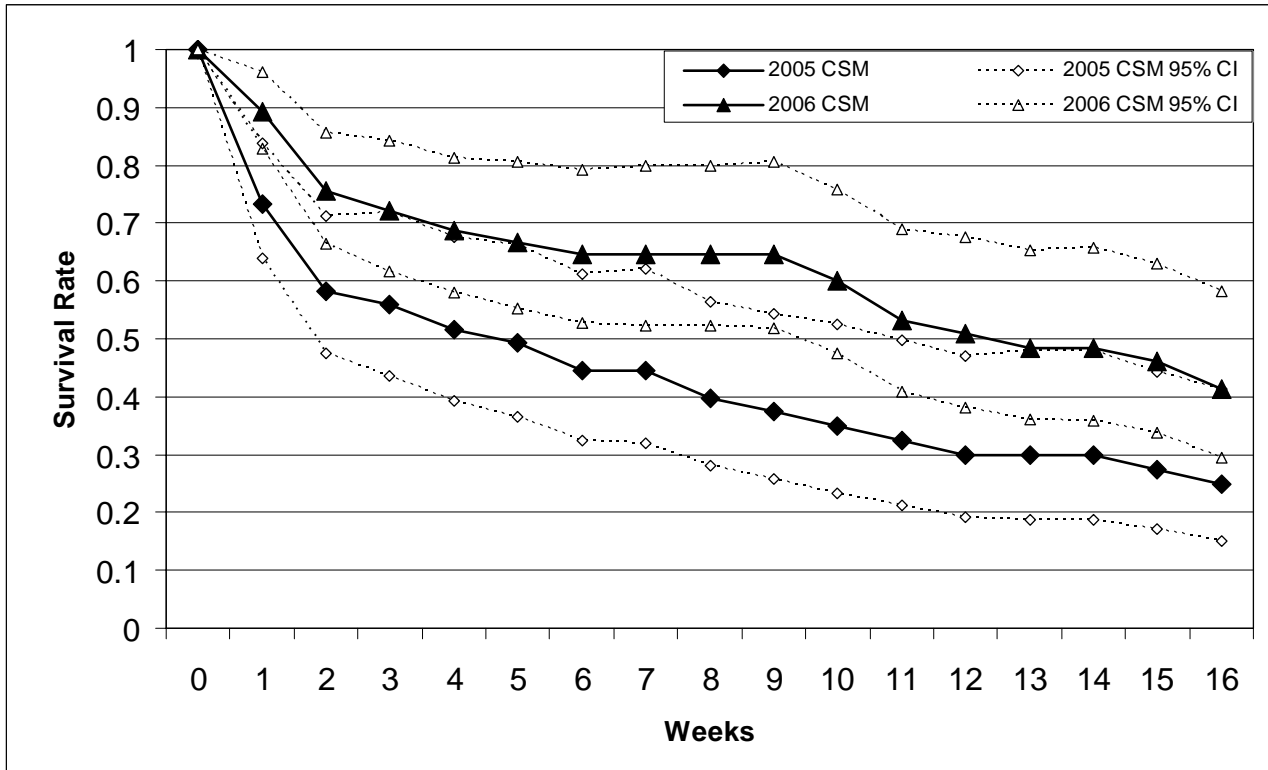


Figure 18. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for domestically-hatched (D-H) radio-marked greater sage-grouse chicks during 2005 ($n = 26$) and 2006 ($n = 30$) in Moffat County, Colorado (Log-rank $\chi^2_1 = 0.50$, $P = 0.4793$). Survival rate is estimated from the adoption age of the D-H chick to 16 weeks post introduction into wild broods.

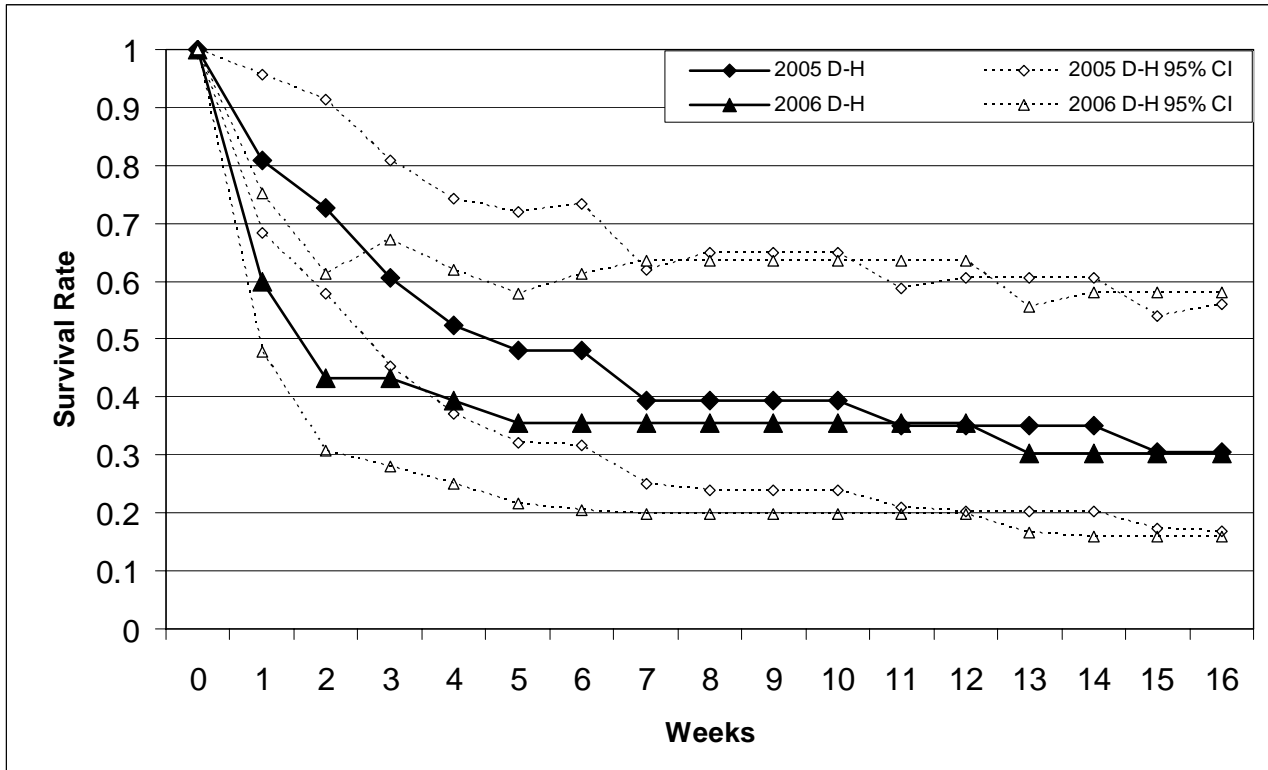


Figure 19. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for domestically-hatched (D-H) radio-marked greater sage-grouse chicks raised from 1 to 4 days of age (Treatment 1: TRT1) during 2005 ($n = 13$) and 2006 ($n = 23$) in Moffat County, Colorado (Log-rank $\chi^2_1 = 0.68$, $P = 0.4180$). Survival rate is estimated from the adoption age of the D-H chick to 16 weeks post introduction into wild broods.

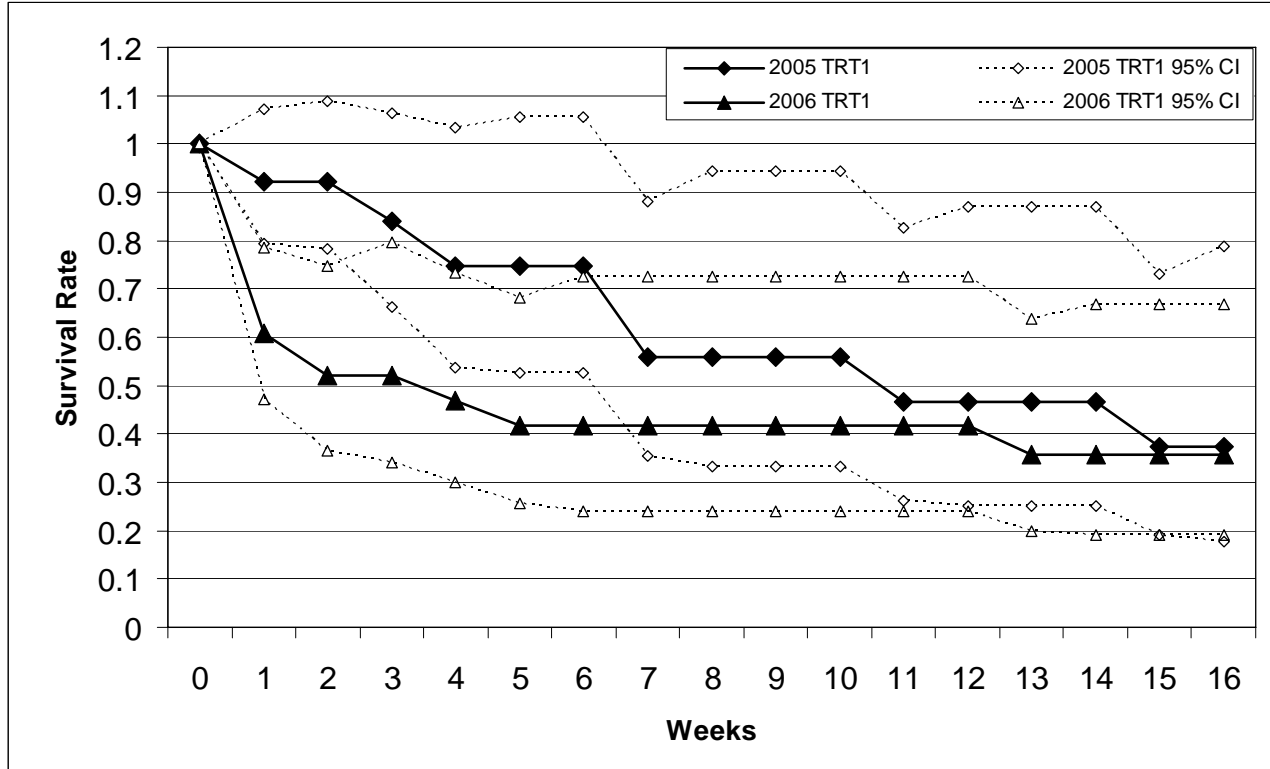


Figure 20. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for domestically-hatched (D-H) radio-marked greater sage-grouse chicks raised from 5 to 11 days of age (Treatment 2: TRT2) during 2005 ($n = 13$) and 2006 ($n = 7$) in Moffat County, Colorado. Survival rate is estimated from the adoption age of the D-H chick to 16 weeks post introduction into wild broods.

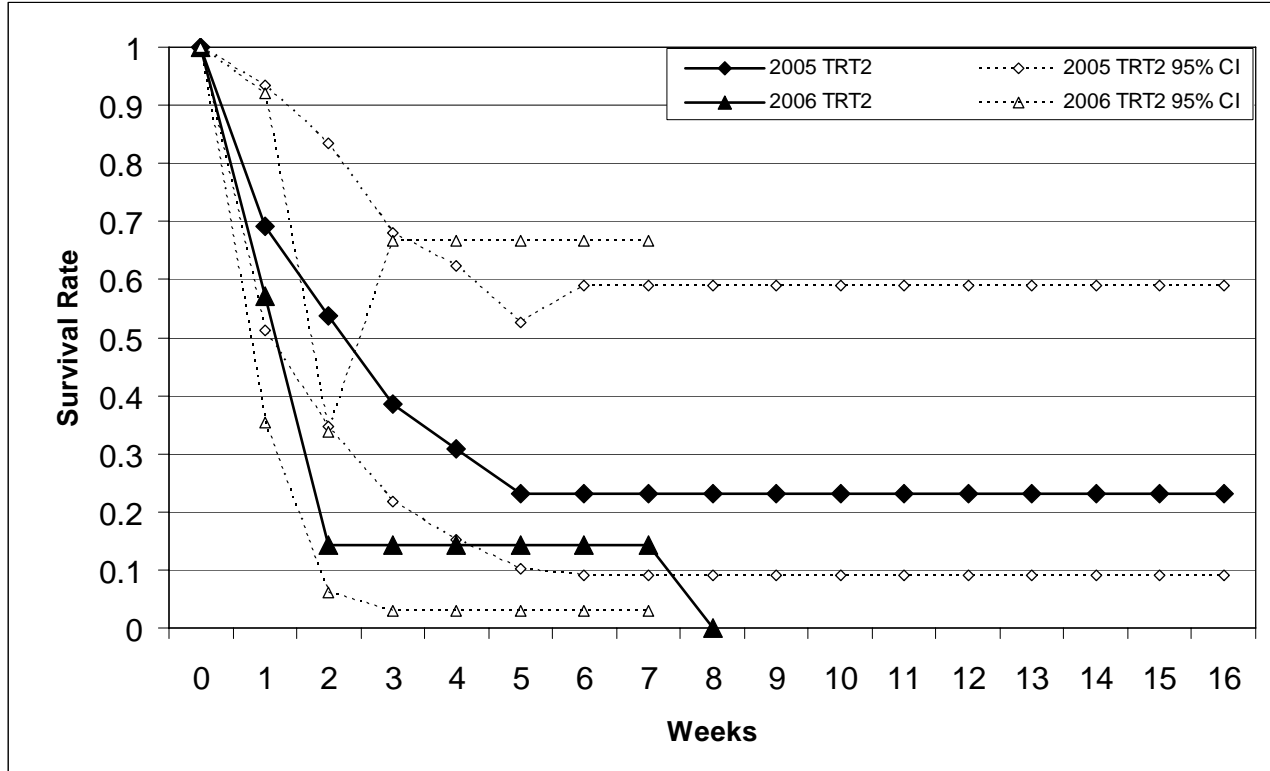


Table 18. Greater sage-grouse broods and chicks radio-marked and monitored during the spring and summer in Moffat County, Colorado, 2005-2006.

	Axial Basin/ Danforth Hills	Cold Springs Mountain	Total
Total Broods	41	39	80
Radio-marked Broods	40	39	79
Total Chicks Radio-marked ^a	206	160	366
Wild Chicks Radio-marked ^b	134	132	266
Domestic Chicks Radio-marked ^c	53	14	67
Total Chicks PIT Tagged ^d	130	116	246
PIT tagged chicks Radio-marked ^e	18	9	27
Censored Radio-marked Chicks:	45	39	84
Dropped Transmitter	4	2	6
Human Error	3	0	3
Radio-failure ^f	11	7	18
Missing/ Unaccounted for	27	30	57

^a Includes all chicks both wild- and domestically-hatched as well as those removed from further survival analysis.

^b Includes all wild-hatched chicks used in the survival analyses.

^c Includes all domestically-hatched chicks (including the 11 that had been removed from further survival analysis due to mortalities within the 48 after introduction into wild broods).

^d Includes only those chicks captured and marked at 1-3 days post-hatch.

^e Refers to those chicks PIT-tagged at 1-3 days post-hatch and then caught and radio-marked at either approximately 60- or 100-days of age.

^f Radios that were confirmed to have failed due to signal weakness or observation of dead radio on sighted or captured chick.

Figure 21. Estimated weekly Kaplan-Meier survival rate estimates of radio-marked greater sage-grouse broods within the Axial Basin (AB) ($n = 40$) and Cold Springs Mountain (CSM) ($n = 39$) study areas to 16 weeks of age in Moffat County, Colorado 2005-2006 (Log-rank $\chi^2_1 = 0.37$, $P = 0.5429$). Mean brood survival rate estimate for northwest Colorado is 48.1%.

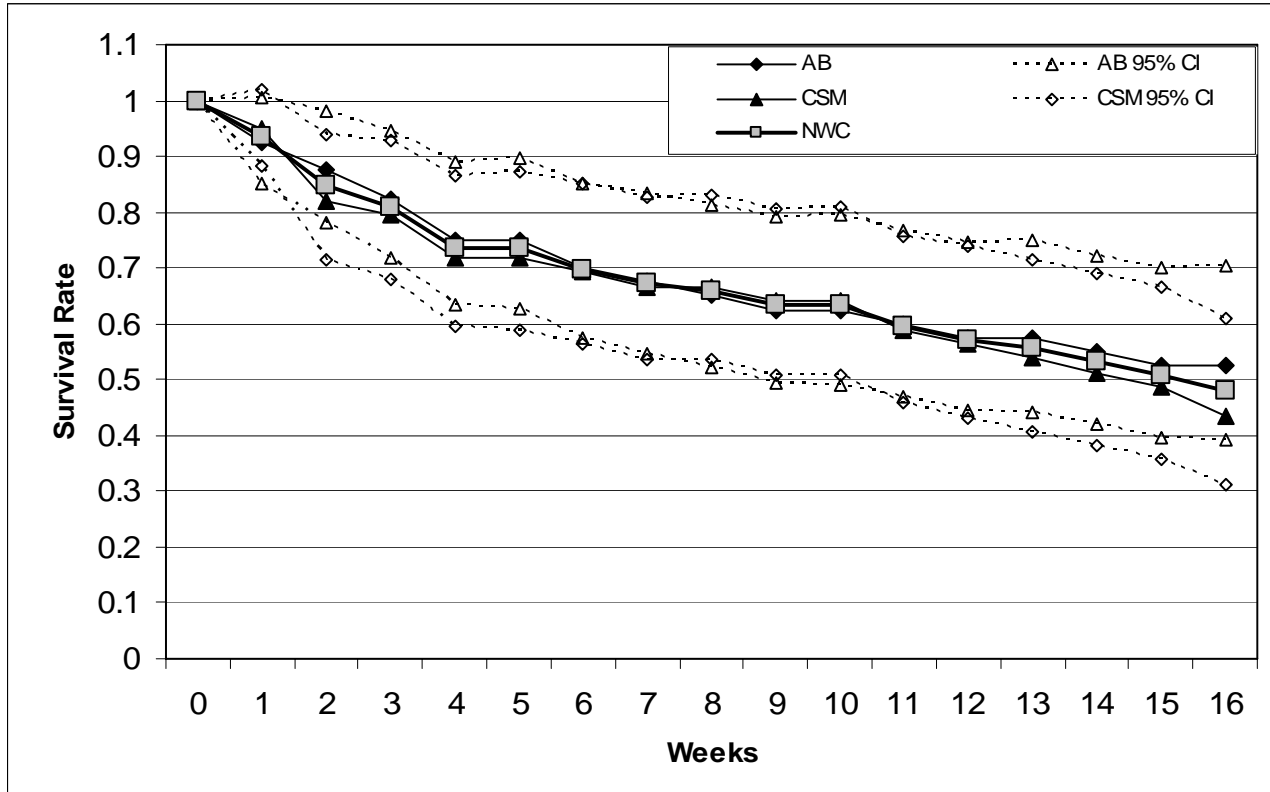


Figure 22. Estimated weekly Kaplan-Meier survival rate estimates of radio-marked greater sage-grouse chicks (both domestically-hatched and wild-hatched) within the Axial Basin (AB) ($n = 179$) and Cold Springs Mountain (CSM) ($n = 143$) study areas to 16 weeks of age in Moffat County, Colorado 2005-2006 ($\text{Log-rank } \chi^2_1 = 1.73, P = 0.1884$). Mean chick survival rate estimate for northwest Colorado is 38.8%.

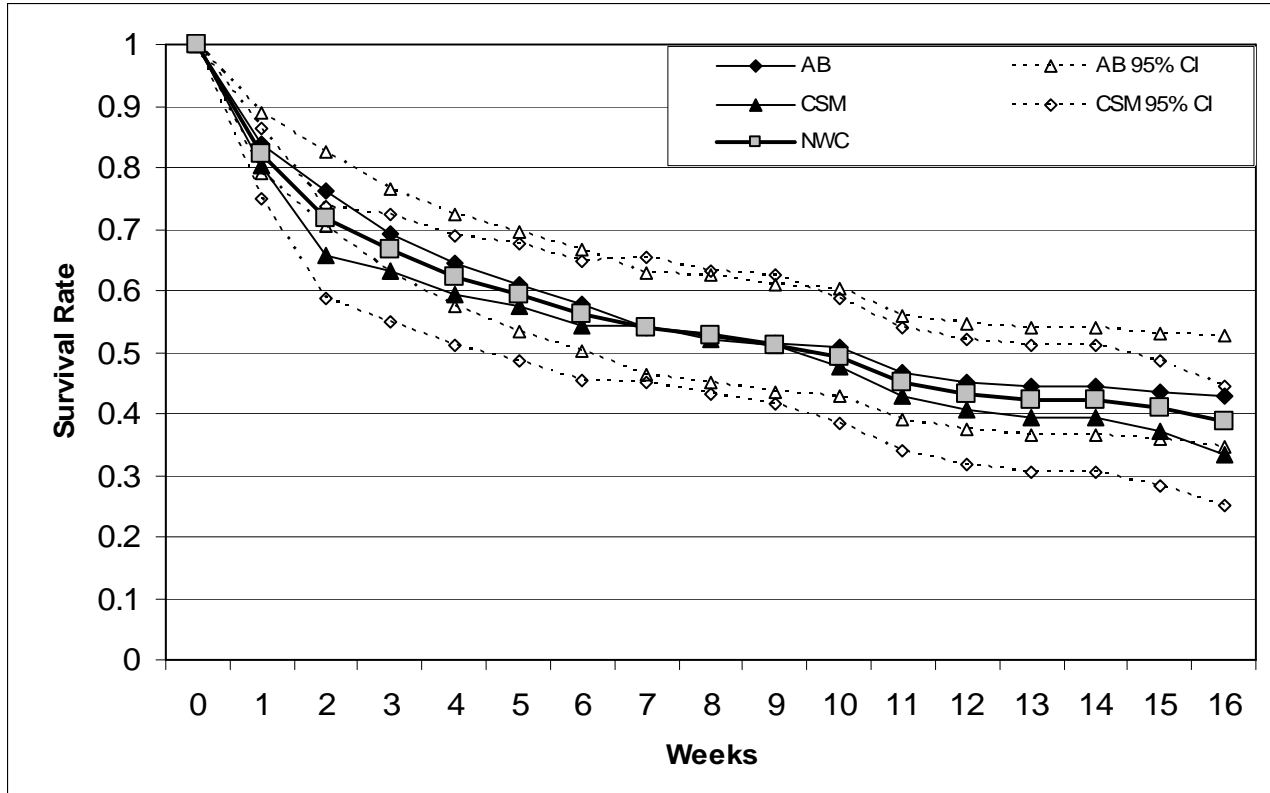


Figure 23. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) of radio-marked greater sage-grouse chicks (wild-hatched) from hatch to 16 weeks of age in the Axial Basin (AB) ($n = 134$) and Cold Springs Mountain (CSM) ($n = 132$) study areas in Moffat County, Colorado 2005-2006 (Log-rank $\chi^2_1 = 2.52$, $P = 0.1125$).

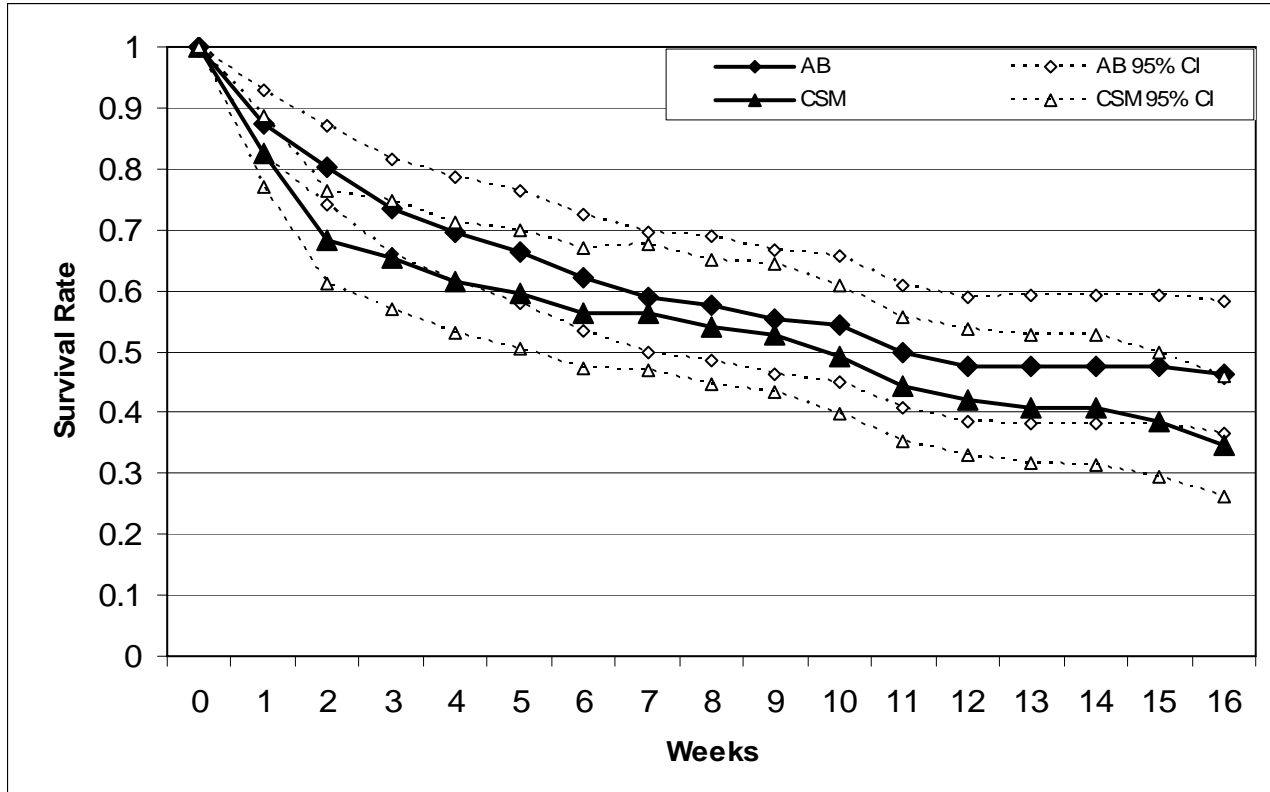


Figure 24. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) of wild-hatched (W-H) ($n = 266$) and domestically-hatched (D-H) ($n = 56$) radio-marked greater sage-grouse chicks from hatch (or adoption date for D-H chicks) to 16 weeks of age in Moffat County, Colorado 2005-2006 (Log-rank $\chi^2_1 = 4.78$, $P = 0.0287$).

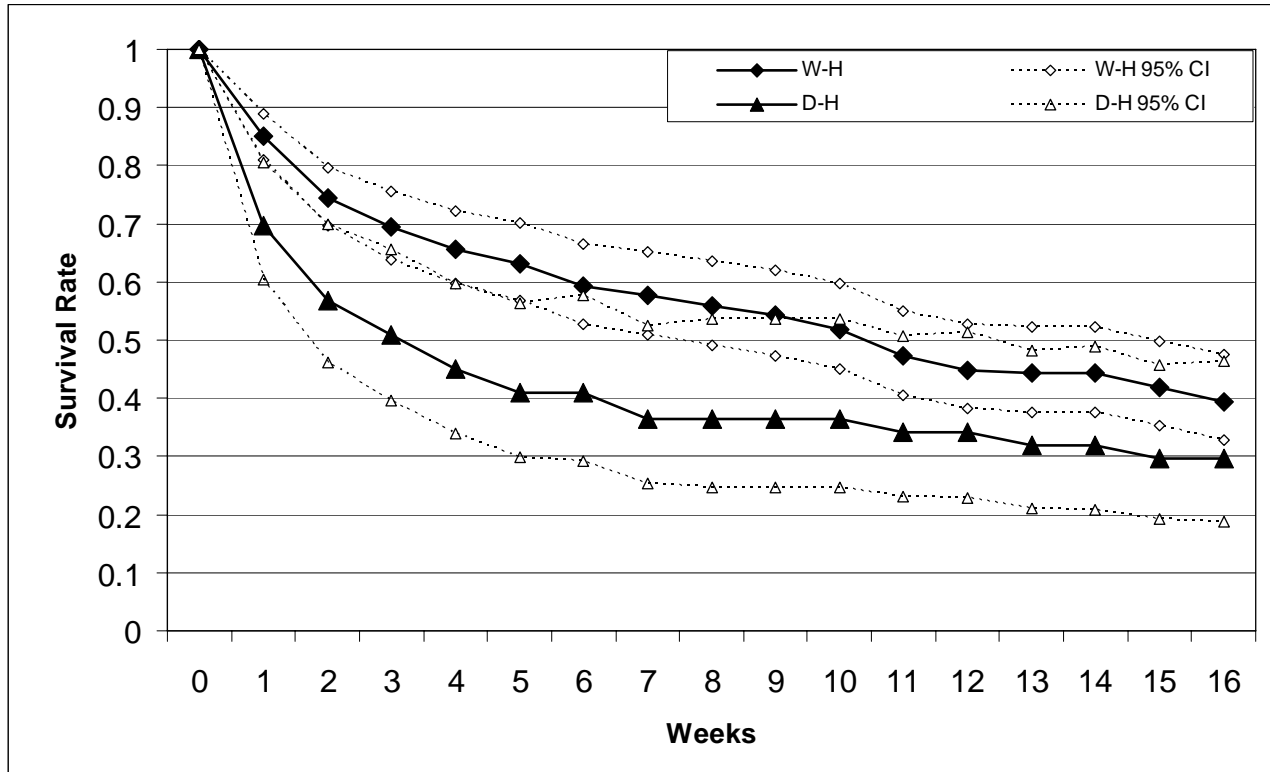


Figure 25. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for domestically-hatched (D-H) radio-marked greater sage-grouse chicks raised from 1 to 4 days of age (Treatment 1: TRT1) ($n = 36$) and 5 to 9 days of age (Treatment 2: TRT2) ($n = 20$) in Moffat County, Colorado 2005-2006 (Log-rank $\chi^2_1 = 2.92$, $P = 0.0875$).

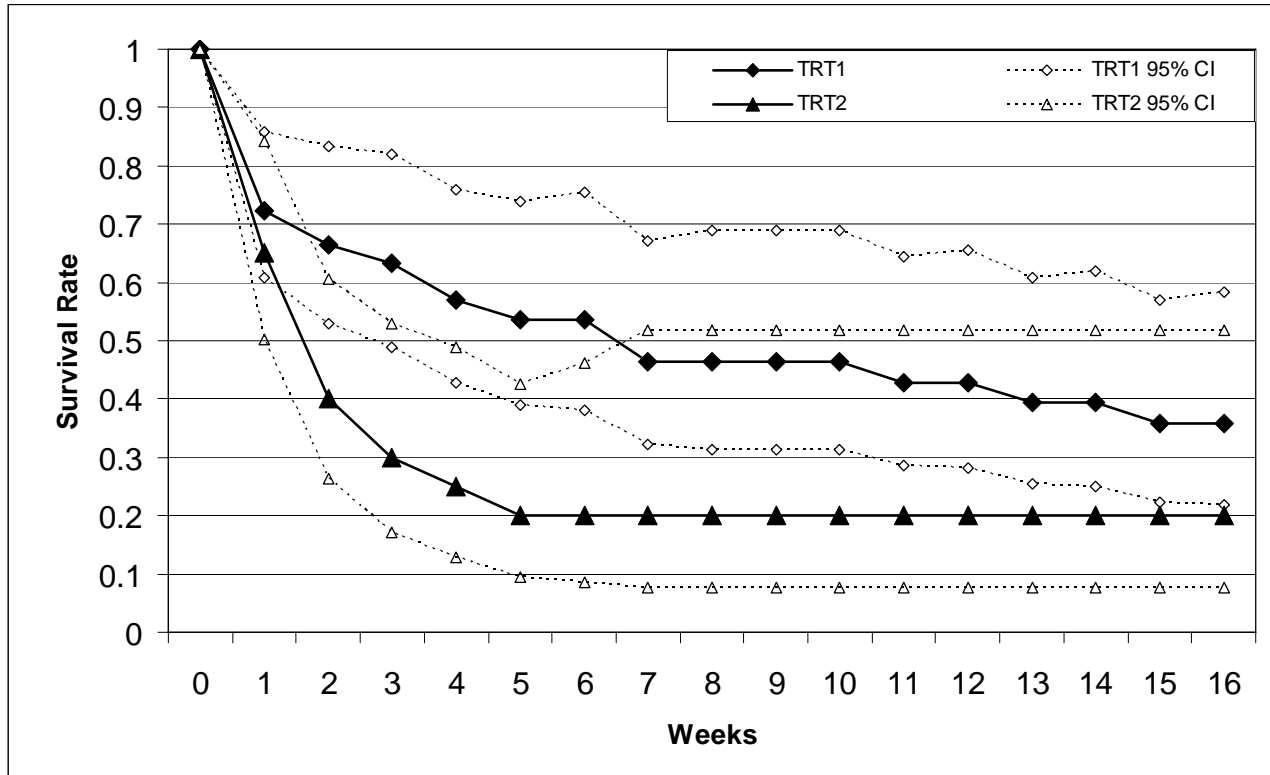


Figure 26. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for domestically-hatched (D-H) radio-marked greater sage-grouse chicks raised from 1 to 4 days of age (Treatment 1: TRT1) ($n = 36$) and wild-hatched (W-H) ($n = 266$) chicks in Moffat County, Colorado 2005-2006 (Log-rank $\chi^2_1 = 0.61$, $P = 0.4360$).

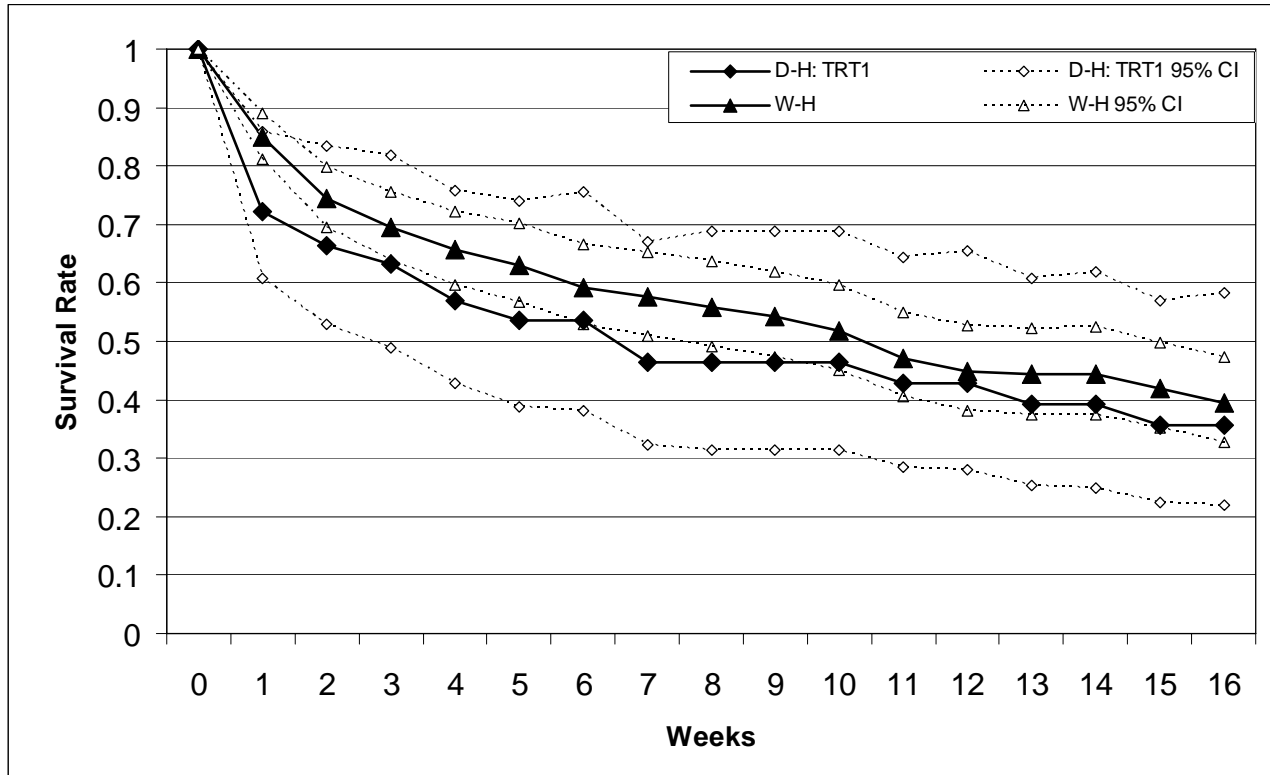


Figure 27. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for domestically-hatched (D-H) radio-marked greater sage-grouse chicks raised from 5 to 11 days of age (Treatment 2: TRT2) ($n = 20$) and wild-hatched (W-H) ($n = 266$) chicks in Moffat County, Colorado 2005-2006 (Log-rank $\chi^2_1 = 14.92$, $P = 0.0002$).

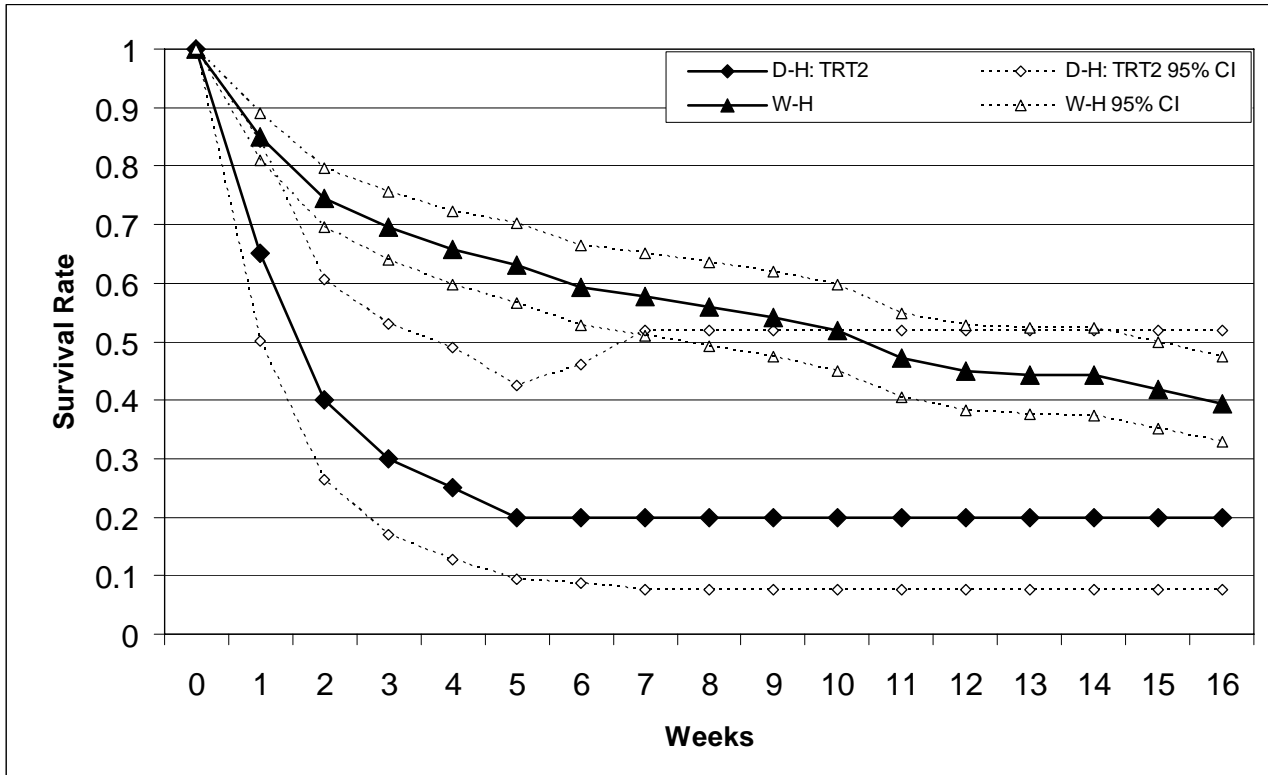


Figure 28. Estimated weekly Kaplan-Meier survival rate estimates with 95% confidence intervals (CI) for wild broods with domestically-hatched greater sage-grouse chicks introduced into them (D-H Broods) ($n = 24$) and wild broods ($n = 55$) in Moffat County, Colorado 2005-2006 (Log-rank $\chi^2_1 = 0.02$, $P = 0.8944$).

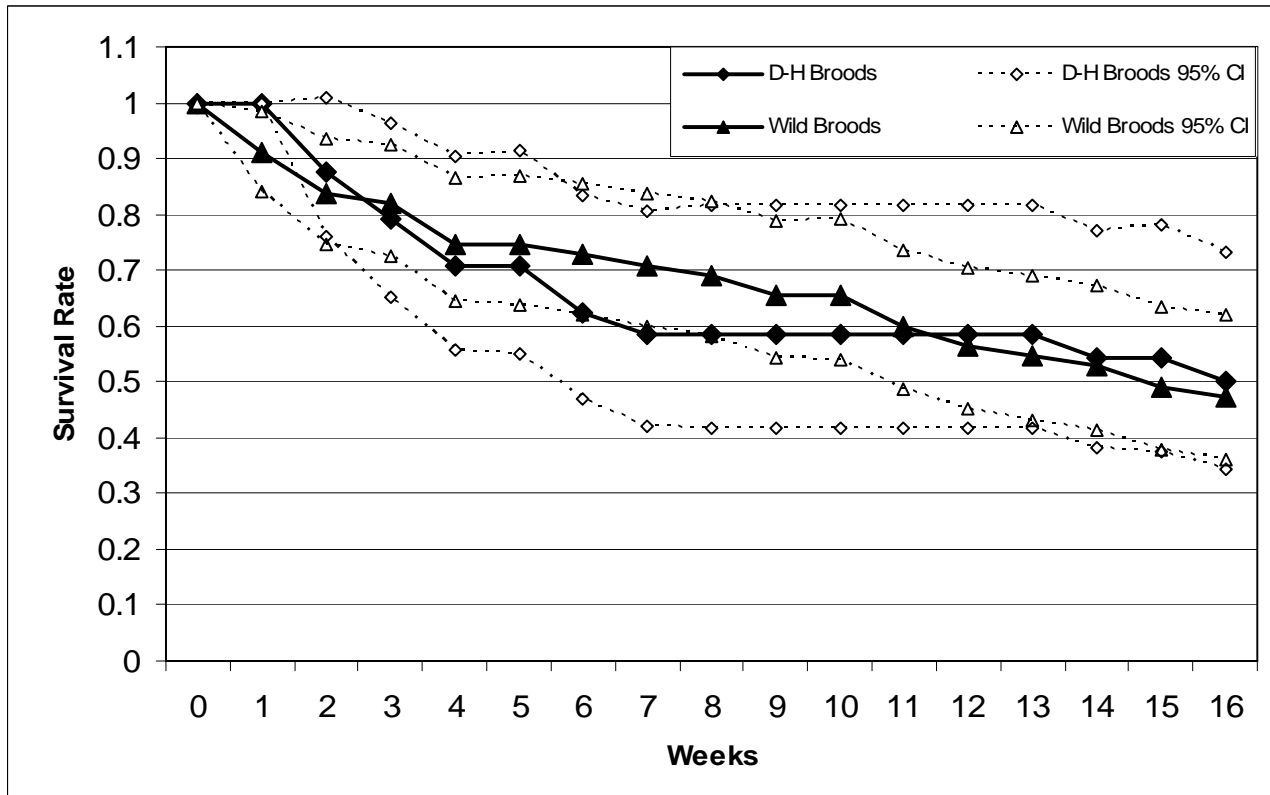


Table 19. Known^a and random^b juvenile greater sage-grouse captured during September and October 2006 and radio-marked with adult collars in Moffat County, Colorado.

	Axial Basin/ Danforth Hills	Cold Springs Mountain	Northwest Colorado
Females			
Known	13	12	25
Random	6	8	14
Total	19	20	39
Males			
Known	10	4	14
Random	0	2	2
Total	10	6	16
Total			
Known	23	16	39
Random	6	10	16
Total	29	26	55

^a Known refers to juveniles marked (either with a chick transmitter or PIT tag) at 1-3 days post-hatch.

^b Random refers to juveniles of unknown parentage (female unknown) and origin (nest location unknown), and captured opportunistically.

Table 20. Average chick hatch weights, second recapture weights, and average fall juvenile capture weights of known hatch-year greater sage-grouse in Moffat County, Colorado 2005-2006. Weights are reported with standard error, range of values, and sample sizes.

	Initial Capture		Second Recapture		Fall Juvenile Capture		
	Average Age (days)	Average Weight (grams)	Average Age (days)	Average Weight (grams)	Average Age (days)	Female Weight (grams)	Male Weight (grams)
2005							
Domestically-Hatched	1.0	30.1 (\pm 0.4) (25.4 – 34.0) (n = 47)	52.0 (49 – 56)	556.0 (\pm 36.0) (458 – 714) (n = 6)	119.3 (117-120)	856 (n = 1)	1570.7 (\pm 113.3) (1348 – 1718) (n = 3)
Axial Basin/ Danforth Hills	2.1 (1 – 3)	31.9 (\pm 0.2) (27 – 40) (n = 120)	50.5 (47 – 56)	645.7 (\pm 20.5) (474 – 866) (n = 30)	124.2 (107 – 148)	1177.1 (\pm 26.5) (972 – 1364) (n = 20)	1663.4 (\pm 43.6) (1504 – 1846) (n = 10)
Cold Springs Mountain	1.8 (1 – 6)	31.25 (\pm 0.5) (23 – 40) (n = 64)	52.2 (48 – 65)	711.2 (\pm 31.1) (486 – 1054) (n = 20)	115.2 (107 – 126)	1227.7 (\pm 17.2) (1188 – 1282) (n = 6)	1679.3 (\pm 33.0) (1620 – 1734) (n = 3)
Northwest Colorado	2.01 (1 – 6)	31.7 (\pm 0.2) (23 – 40) (n = 184)	51.1 (47 – 65)	671.9 (\pm 17.9) (474 – 1054) (n = 50)	122.1 (107 – 148)	1188.8 (\pm 21.0) (972 – 1364) (n = 26)	1667.1 (\pm 33.8) (1504 – 1846) (n = 13)
2006							
Domestically-Hatched	1.0	28.79 (\pm 0.4) (22.2 – 35.8) (n = 55)	51.6 (46 – 69)	627.3 (\pm 38.9) (457 – 768) (n = 7)	122	1116.0 (\pm 30.0) (1086 – 1146) (n = 2)	1611.3 (\pm 67.1) (1432 – 1722) (n = 4)
Axial Basin/ Danforth Hills	1.6 (1 – 3)	31.6 (\pm 0.3) (26 – 40) (n = 104)	44.2 (34 – 56)	529.9 (\pm 24.6) (344 – 982) (n = 35)	117.8 (105 – 128)	1112.5 (\pm 19.6) (998 – 1192) (n = 11)	1552.2 (\pm 45.6) (1424 – 1710) (n = 6)
Cold Springs Mountain	3.2 (1 – 7)	32.9 (\pm 0.6) (22 – 52) (n = 134)	42.8 (32 – 58)	501.4 (\pm 22.5) (248 – 912) (n = 37)	113.4 (100 – 138)	1113.2 (\pm 30.4) (976 – 1280) (n = 10)	1605.4 (\pm 29.2) (1424 – 1674) (n = 6)
Northwest Colorado	2.5 (1 – 7)	32.3 (\pm 0.3) (22 – 32) (n = 238)	43.5 (32 – 58)	515.3 (\pm 16.6) (248 – 982) (n = 72)	117.3 (100 – 138)	1112.9 (\pm 17.3) (976 – 1280) (n = 21)	1528.4 (\pm 49.7) (1016 – 1710) (n = 12)

Table 20. Continued

		Initial Capture		Second Recapture		Fall Juvenile Capture		
		Average Age (days)	Average Weight (grams)	Average Age (days)	Average Weight (grams)	Average Age (days)	Female Weight (grams)	Male Weight (grams)
Total	Domestically-Hatched	1	29.4 (\pm 0.3) (22.2 – 35.8) (<i>n</i> = 102)	51.3 (46 – 69)	594.4 (\pm 27.6) (457 – 768) (<i>n</i> = 13)	121.2 (117 – 126)	1029.3 (\pm 88.4) (856 – 1146) (<i>n</i> = 3)	1593.9 (\pm 56.5) (1348 – 1722) (<i>n</i> = 7)
	Axial Basin/ Danforth Hills	1.9 (1 – 3)	31.8 (\pm 0.2) (26 – 40) (<i>n</i> = 224)	47.3 (34 – 56)	583.4 (\pm 17.7) (344 – 982) (<i>n</i> = 65)	122.0 (105 – 148)	1154.2 (\pm 19.1) (972 – 1364) (<i>n</i> = 31)	1625.7 (\pm 36.3) (1424 – 1846) (<i>n</i> = 15)
	Cold Springs Mountain	2.8 (1 – 7)	32.3 (\pm 0.4) (22 – 52) (<i>n</i> = 198)	46.1 (32 – 65)	575.0 (\pm 22.5) (248 – 1054) (<i>n</i> = 57)	114 (100 – 138)	1156.1 (\pm 24.2) (976 – 1282) (<i>n</i> = 16)	1614.0 (\pm 25.6) (1444 – 1734) (<i>n</i> = 10)
	Northwest Colorado	2.3 (1 – 7)	32.0 (\pm 0.2) (22 – 52) (<i>n</i> = 422)	46.7 (32 – 65)	579.5 (\pm 14.0) (248 – 1054) (<i>n</i> = 122)	118.9 (100 – 148)	1154.9 (\pm 14.9) (972 – 1364) (<i>n</i> = 47)	1621.0 (\pm 23.7) (1424 – 1846) (<i>n</i> = 25)